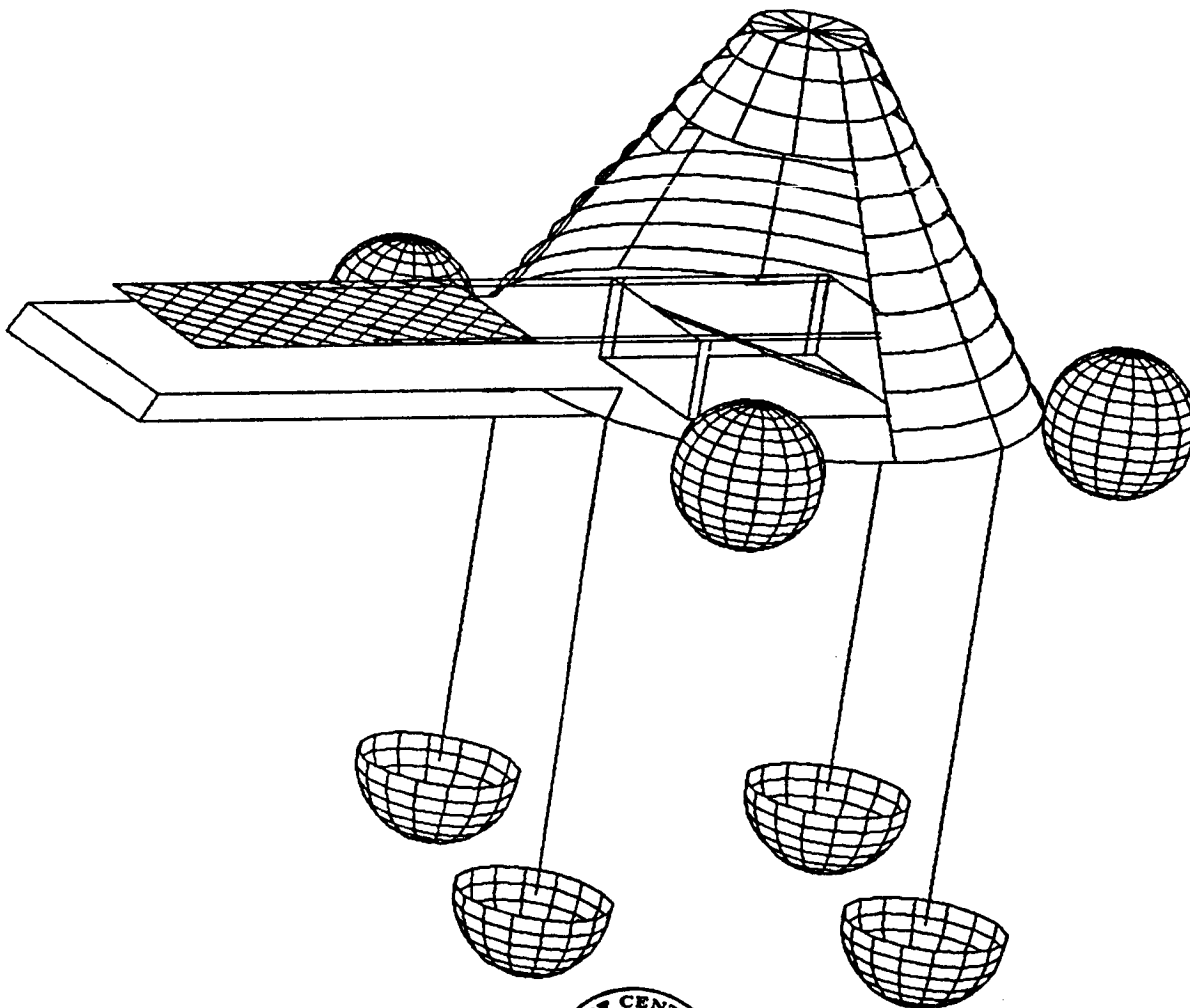


# DESIGN, BUILDING, AND TESTING OF THE POST LANDING SYSTEMS for the ASSURED CREW RETURN VEHICLE



## NASA/USRA FINAL REPORT 1991

UNIVERSITY OF CENTRAL FLORIDA  
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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**DESIGN, BUILDING, AND TESTING  
OF THE POST LANDING SYSTEMS  
for the  
ASSURED CREW RETURN VEHICLE**

**UNIVERSITY OF CENTRAL FLORIDA  
FINAL REPORT**

**Submitted To:  
THE NATIONAL AERONAUTICS  
AND SPACE ADMINISTRATION  
and  
THE UNIVERSITIES SPACE  
RESEARCH ASSOCIATION**

## Foreword

During the 1990-1991 academic year the Aerospace and Mechanical Engineering senior design students continued the design and testing of the SPACE STATION ASSURED CREW RETURN VEHICLE (ACRV). Engineering Design 4501 and 4502 cater to a variety of design interests of aerospace and mechanical engineering students at the University of Central Florida (UCF). The output of the course sequence consists of (a) oral design reviews, (b) a working model of the design and (c) the final report containing test results.

The goal of this year's project, conducted with the Space Station ACRV Project Office at Kennedy Space Center (KSC), was to extend last year's work on the conceptual design of the water landing version of the ACRV. Design emphasis was placed on the post landing tasks associated with the Kennedy Space Center mission. The fall semester was spent doing a detailed design of a one-fifth scale model of the ACRV vehicle and the egress and stabilization systems. In the spring semester the scale model was built at UCF, and tested at UCF and the O.H. Hinsdale Water Test Facility at Oregon State University in Corvallis, Oregon. Travel to the test site and cost associated with leasing the facility were sponsored by Rockwell International, Inc. The tests clearly demonstrated design concepts that worked and deserve further study, as well as design concepts that did not show great promise. In each case valuable information was obtained and future work was more clearly defined.

At the end of fall semester a design review was conducted at Kennedy Space Center. At the end of spring semester the results of the water testing were reviewed at Kennedy Space Center and at Johnson Space Center. These reviews were attended by NASA engineers and engineers employed by NASA contractors. The comments received from practicing engineers during this review process have greatly influenced the content of this report and increased the engineering knowledge of the students.

The ACRV design team consisted of 24 engineering seniors. Ken Hosterman served as graduate teaching assistant during both fall and spring semesters. During the spring semester Ken was assisted by Pam Armitage, the designated graduate teaching assistant for the coming academic year. Ken's efforts coordinating and guiding the interfaces of the ACRV were invaluable. Twenty seniors participated during the fall semester. Seven seniors from the fall semester group continued in the model building and testing during spring semester. They were joined by four additional seniors for a total of eleven participating design students during spring semester. Ken Hosterman had the major task of integrating the design and test reports from fall and spring semesters into this final report. He was ably assisted by Pam Armitage during the documentation effort. Michael Ballentine designed and created the display model of the ACRV during spring semester.

John Brooks and David Van Sickle were selected to receive Rockwell Fellowships beginning summer semester 1991. They will continue in graduate school at UCF working on advanced ACRV designs.

We gratefully acknowledge support from the National Aeronautics and Space Administration, the Universities Space Research Association and Rockwell International in the NASA/USRA Advanced Space Design Program. Special recognition is due Gordon Johnston, Program Manager of University Space Programs; and Sherry McGee, University Programs, NASA Headquarters, Washington, D.C.; and J.R. (Dick) Lyon, Space Station Project Manager at KSC. At USRA in Houston special recognition is due John Sevier, Director and Carolynne Hopf, Deputy Director, Educational Programs; and Barbara Rumbaugh, Senior Project Administrator of Advanced Design Programs. At Rockwell International in Downey, CA special recognition is due Dr. Peter Kondis, Program Development Manager, Advanced Programs; and Don Morris, Senior Engineer. For practical operational guidance in search and rescue matters we greatly appreciate the advice of Col. George D. (Dave) Phillips, Lt.Col. Ralph Abravaya, Lt.Col. Chris Malbon, Maj. Scott Hogrefe, and Maj. Bill Heitzman from Patrick AFB. For his advice on medical matters associated with ACRV operations we thank Dr. Daniel Woodard of the Bionetics Corporation medical staff at KSC. We greatly appreciate the efforts of Jane Page, Dorothy Price, Donna Atkins, Ramon Budet, Cristal Woods, and Joann Ratliff for guidance and help searching out technical documentation at the KSC library. For support and advice on building the ACRV scale model we are grateful to Ed Guard and Tom Wilkes of Guard-Lee, Inc. We are indebted to Greg Opresko, Jim Aliberti, Dennis Matthews, Jose Alonso, Cathy Parker, Bruce Larsen, and Dave Springer of KSC for their technical support and encouragement throughout the academic year. For their attendance and valuable comments at our design reviews we thank our local industry representatives Joyanne Craft, Rockwell International; Gene Baker, Lockheed Space Operations; and Keith Chandler, Boeing Aerospace. We are especially indebted to Glenn Parker, ACRV Project Manager at KSC, for his technical guidance and enthusiasm in establishing goals and providing constructive critique of our work.

Professor Loren A. Anderson

June 10, 1991

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## **LIST OF ACRONYMS**

ACM	- Apollo Command Module
ACRV	- Assured Crew Return Vehicle
CEBA	- Combined Engineering and Business Administration
CERC	- Coastal Engineering Research Center
CG	- Center of Gravity
DSJM	- Dual Scissor Jack Mechanism
DUPS	- Deployable Underwater Parachute System
EEC	- Emergency Egress Couch
FLIPEM	- Four Link Injured Personnel Egress Mechanism
FPCM	- Four Piston-Cylinder Mechanism
IBM	- Ironing Board Mechanism
IPM	- Inclined Plane Mechanism
KSC	- Kennedy Space Center
LVDT	- Linear Variable Differential Transducer
LVRT	- Linear Variable Reluctance Transducer
NASA	- National Aeronautics and Space Administration
OTRC	- Offshore Technology Research Center
PVC	- Polyvinyl Chloride
RES	- Rapid Egress System
RLM	- Roller Link Mechanism
SCRAM	- Station Crew Return Alternative Method
TSSM	- Three Slider Support Mechanism
UCF	- University of Central Florida
WTF	- Water Test Facility

**DESIGN, BUILDING, AND TESTING  
OF THE POST LANDING SYSTEMS  
for the  
ASSURED CREW RETURN VEHICLE**

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**DESIGN, BUILDING, AND TESTING  
OF THE POST LANDING SYSTEMS  
for the  
ASSURED CREW RETURN VEHICLE**

**EXECUTIVE SUMMARY**

The design, building, and testing of the post landing support systems for a water landing Assured Crew Return Vehicle (ACRV) are presented. One ACRV will be permanently docked to Space Station Freedom, fulfilling NASA's commitment to Assured Crew Return Capability in the event of an accident or illness. The configuration of the ACRV is based on an Apollo Command Module (ACM) derivative. The 1990-1991 effort concentrated on the design, building and testing of a one-fifth scale model of the egress and stabilization systems. The objective was to determine the feasibility of: 1) stabilizing the ACM out of the range of motions which cause sea sickness and 2) the safe and rapid removal of a sick or injured crewmember from the ACRV. The development of the ACRV post landing systems model was performed at the University of Central Florida with guidance from the Kennedy Space Center ACRV program managers. Work was conducted in the following areas:

- \* ACRV Model Construction
- \* Water Test Facility Identification
- \* Rapid Egress Systems
- \* Stabilization Control Systems

The ACRV model construction is presented in Section I. A one-fifth scale working model of the ACM was built to accommodate the egress and stabilization systems for testing. The geometric and dynamic characteristics of the model were established through consultations with Rockwell International - Space Systems Division. The center of gravity and mass moment of inertia are modelled and varied using a system of flat circular plates. The model is constructed from a fiberglass sandwich material. The upper and lower halves of the model are held together by a four bolt and T-nut system with a waterproof gasket for sealing.

Water test facility selection is discussed in Section II. As a result of this search, stabilization tests on the ACRV model were conducted at the O.H. Hinsdale Wave Research Laboratory at Oregon State University in Corvallis, Oregon. The dimensions of the wave pool were satisfactory for testing the model in all configurations. Sea states two, three, and four were simulated for testing purposes. Support, visualization, and data



and data acquisition systems were provided at the facility. Financial support for travel, lodging, and facility fees was provided by a grant from Rockwell International.

The rapid egress system is presented in Section III. The Four Link Injured Personnel Egress Mechanism (FLIPEM), designed in the previous academic year, was built and tested. FLIPEM consists of three parts: the lift mechanism, extension support mechanism, and the restraint mechanism. The lift mechanism employs the use of two compressed air cylinders each capable of lifting the entire system. When activated by radio control the cylinders located beneath the couch platform extend the FLIPEM the required horizontal and vertical distance from the model floor to the hatch location. Built-in ratchets ensure one way motion and can be released to allow for manual retraction. The Three Slider Support Mechanism (TSSM) provides the extension support of the couch platform through the hatch to a distance away from the model. The sliders, similar to those used on a tool box, are extended by means of a reversible electric motor and a cable-pulley system. The restraint mechanism employs a spring-loaded hook, activated by radio control, to maintain the FLIPEM in the stowed position and a series of locking pins to prevent movement of the couch platform during FLIPEM operation.

ACRV stabilization control systems are discussed in Section IV. The stabilization system that was built and tested consists of three parts: the attitude ring, the underwater parachute system, and testing equipment. The attitude ring envisioned for the actual ACRV is comprised of inflatable spheres similar to the orientation spheres used during the Apollo program. The inflatable spheres were modelled using eight inch diameter tether balls, connected to eye hooks located around the periphery of the model. Nylon parachutes, with diameters of one to two and a half feet, were fabricated, attached to the eye hooks on the model with stiff and elastic cables, and tested at the wave facility for response characteristics. Three mechanical accelerometers were attached to the ACRV model floor to measure the vertical, horizontal, and pitch accelerations resulting from parachute deployment in the simulated sea states. Data was recorded using a computerized data acquisition system.

Testing at UCF and O. H. Hinsdale WRL produced four major results. The Four Link Injured Personnel Egress Mechanism and the Three Slider Support Mechanism performed according to design specifications and without interference to other systems. The inflatable spheres that simulate the attitude ring and the underwater parachute stabilization system provided no added stabilizing effect to the model. A system of four arrangements of two Rocker Stoppers, positioned nose-to-nose, and rigidly attached to the model by a long threaded rod was built and tested at the water facility. The Rocker Stopper concept did reduce the pitching motion oscillations below the range associated with seasickness.

## **INTRODUCTION**

- \* Space Station: A New Beginning**
- \* Assured Crew Return Vehicle Concept**
- \* UCF ACRV Designs Developed Previously (1989-1990)**
- \* 1990-1991 UCF ACRV Design Tasks**

## **INTRODUCTION**

### **Space Station: A New Beginning**

**"The Congress hereby declares that it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind..."[1]**

**With these words Congress enacted the National Aeronautics and Space Act which created NASA in 1958 and continues to guide its policies today. Following in the same enthusiasm and determination, President Ronald Reagan, in his State of the Union Message on January 5, 1984, directed NASA to "...develop a permanently manned Space Station and to do it within a decade."**

**This commitment to the future, ripe with intellectual and technical challenge, holds vast opportunities for commercial profit and the preservation of the nation's economic vitality. The Space Station symbolizes America's significant advancements in space and a determination to remain undeterred by the loss of Challenger and her crew.**

**The practical benefits of the Space Station will be many, serving a diverse range of functions. A few of these functions are anticipated to be:**

- \* A laboratory in space, for the development of new technologies and the conduct of science,**
- \* A permanent observation post used for the study of Earth sciences, as well as to peer out to the edge of the universe,**
- \* A facility where payloads and spacecraft can be maintained and repaired,**
- \* A location where vehicles can be deployed to their destinations,**
- \* A staging base for future space endeavors.**

**Much progress has already been made in the development of this program. The road ahead will be rigorous and demanding. A unique partnership has been established with Canada, Europe, and Japan to provide elements, that together, will make the Space Station a fully functional reality.**

**The Space Station project symbolizes leadership in space for the United States as a necessary component of civil space policy. Opportunities for private business profits will also improve the national economy. However, the advantages are not just limited to the United States. Because the operation of the Space Station is to be an international effort,**

it will benefit everyone by allowing mankind to move beyond the confines of Earth as never before possible.

### **Assured Crew Return Vehicle Concept**

For years, America's journey into space has demonstrated the benefits associated with working in the unique environment of microgravity. Continuing in this tradition, man has launched an ambitious and far-reaching program to further the advancement of space technology. With Space Station Freedom the United States enters an era marked by a permanent presence in space. Moreover, the space station allows continuous rather than intermittent operations to be conducted in orbit. The space station opens doors to many new methods of research and experimentation. Furthermore, a better opportunity to observe the earth and forecast future trends from a vantage point only partially exploited by previous shuttle missions is assured.

Space Station Freedom is planned to be permanently manned by a crew of four. The crew will be rotated and resupplied by flights of the Orbiter on an interval currently planned for three months [2]. Due to isolation and potentially hazardous conditions involved in space operations, NASA is committed to the policy of Assured Crew Return Capability for space station crews in the event:

1. a medical emergency occurs and an ill, injured, or deconditioned crewmember must be rapidly transported from the space station to a definitive health care facility on earth.
2. a space station catastrophe forces a rapid evacuation of the crew from the station.
3. the National Space Transportation System becomes unavailable, and an orderly evacuation of the crew from the space station becomes necessary.

These events, or Design Reference Missions (DRM's), can be met by a concept known as the Assured Crew Return Vehicle (ACRV). Currently, NASA is considering three classes of ACRV's: water landers, runway landers, and open land, or non-runway, landers.

The task objectives detailed in this report were developed in conjunction with Kennedy Space Center ACRV project managers and are limited to that required for a water landing ACRV and post landing operations. The configuration of the ACRV is based on an Apollo Command Module (ACM) derivative [3]. The designs presented in this report are associated with the development of one-fifth scale working models of the ACRV egress and stabilization systems developed at the University of Central Florida during the 1989-1990 academic year.

## **UCF ACRV Designs Developed Previously (1989-1990)**

The ambulatory nature of returning an ill, injured, or deconditioned crewmember back to earth aboard a water landing ACRV requires new technologies and operational procedures. The possibility of further injury or illness may compromise the mission. Following are general design considerations and solutions suggested by the senior-level Mechanical and Aerospace Engineering Design classes during the 1989-1990 academic year. Design considerations were from the point immediately after splashdown to rescue by recovery forces.

The first consideration was providing crew egress and rescue personnel support subsystems to ensure the safe and rapid removal of an ill or injured crewmember from the ACRV by recovery forces. A Special Purpose Emergency Egress Couch was designed to medically support a sick or injured crewmember during the ACRV mission. This couch provides a self-contained environment and space for necessary medical equipment. To aid in the movement of the couch from the ACRV floor to the hatch location, a Four Link Injured Personnel Egress Mechanism (FLIPEM) was developed. Support to the rescue personnel is provided by the placement and design of properly located handholds, supports, and platforms. The FLIPEM and egress couch are shown in Figure 1.

The second consideration was the proper orientation, attitude control, and stabilization systems required for the ACRV in the marine environment. Experience gained from previous Apollo water landings showed that some sea and weather conditions cause severe discomfort to the crew. In the case of an injured crewman this may cause further aggravation of an already existing injury, or even death. Post landing orientation of the ACRV is achieved through the use of three, 6.2 ft diameter, CO<sub>2</sub> charged balloons similar to that used during the Apollo program. Attitude control systems were designed which automatically deploy three multi-chambered ring segments. One segment resides under the hatch and has a 6x6x3 ft appurtenance to act as a stable platform for the rescue personnel. Multiple underwater parachute assemblies were designed to provide motion reduction through the principles of inertia and viscous drag associated with moving large volumes of water. The integrated orientation, attitude control, and stabilization systems are shown in Figure 2.

The third consideration dealt with providing full medical support to an ill, injured, or deconditioned crewmember aboard the ACRV from the time of separation from the space station to rescue by recovery forces. While living and working on the Space Station, the astronauts will be involved in extra-vehicular activities and other demanding jobs. It is likely that an injury may occur which requires emergency medical care available only at a hospital on earth. Partial medical support, medical support equipment and monitors, and oxygen administration and control systems were addressed. Partial medical support is accomplished by employing the Thomas Transport Pack currently used aboard the Shuttle. Extensive research was performed to select suitable medical support equipment and monitors as required by NASA. Each piece of equipment was integrated into unified

# FLIPEM AND EGRESS COUCH SYSTEM

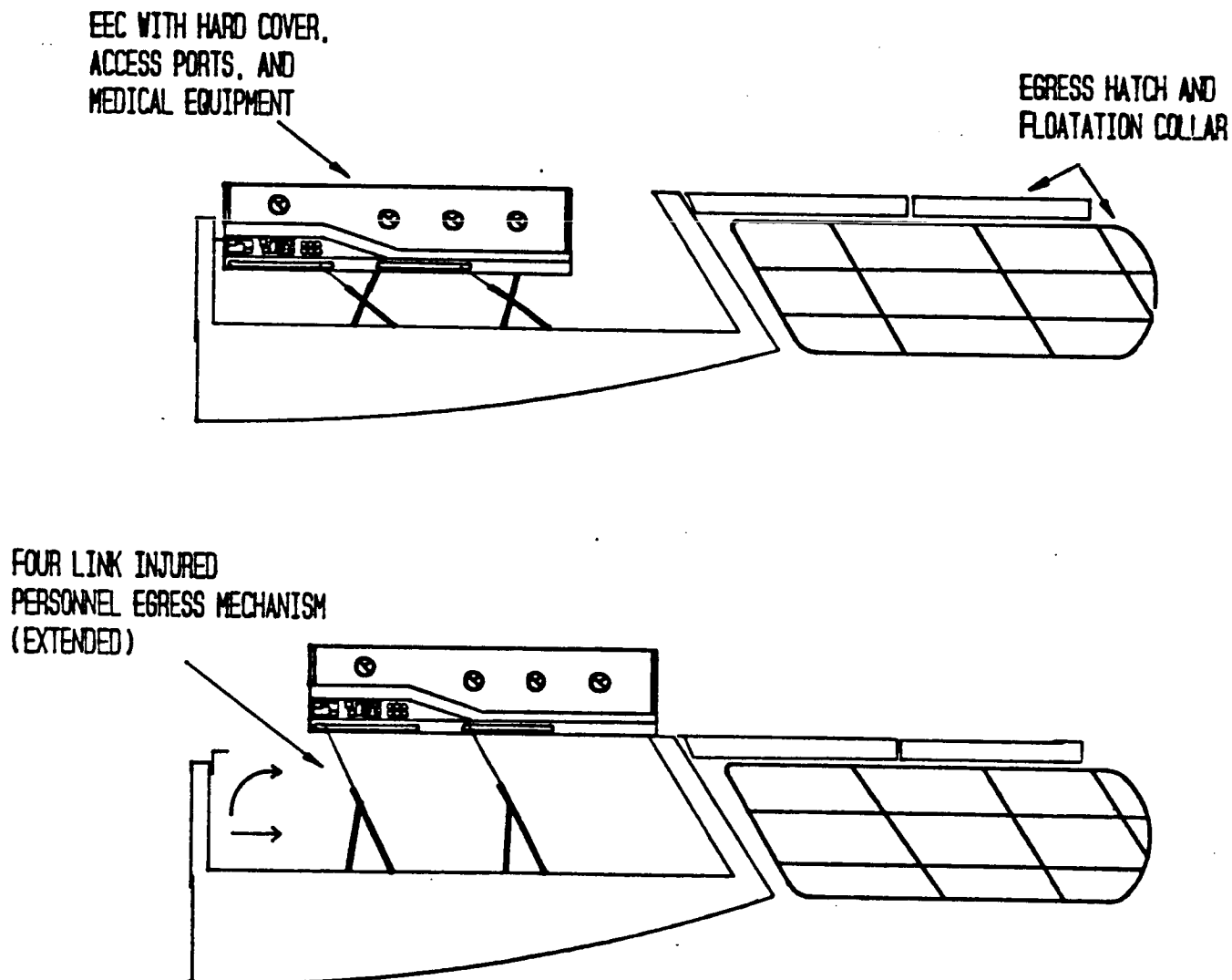


FIGURE 1.

# INTEGRATED ORIENTATION, ATTITUDE CONTROL, AND STABILIZATION SYSTEMS

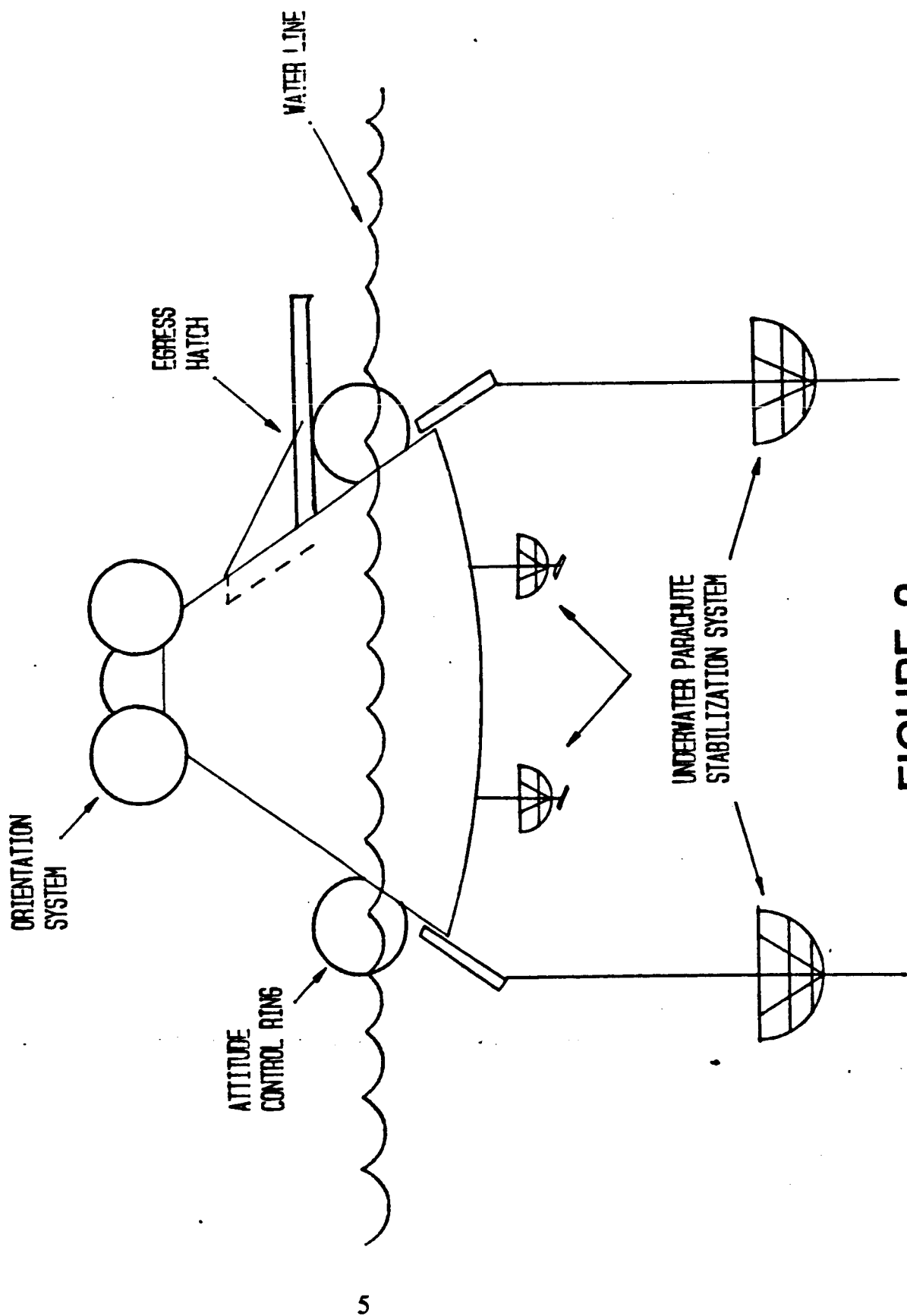


FIGURE 2.

packages and power requirements were addressed. Oxygen is supplied to a deconditioned crewmember, seated at a regular flight couch, by a nasal cannula device and excess oxygen filtered out by an air-dump system. The medical couch is supplied by an independent O<sub>2</sub> system for a period of six hours after egress.

Finally, the fourth consideration provided for the comfort and safety of the entire crew from splashdown to the time of rescue. The rescue team may not arrive at the craft for an extended period of time. Therefore, maintaining the comfort and health of the crew within the ACRV is necessary. Addressed were design solutions for food, water, waste management, atmosphere, contaminant/odor control, and environmental control systems. Food systems chosen were Space Shuttle contingency bars because of proven use and low volume and weight. Water supply systems utilize plastic squeeze bottles. The waste management system is a derivative of the Apollo-style waste bag system. Modifications are necessary to qualify for use by men and women. The standard sea-level atmosphere inside the ACRV is generated by a system using two, 3000 psi tanks of O<sub>2</sub> and N<sub>2</sub>. The contaminant and odor control design uses lithium hydroxide and charcoal filter systems used extensively in the space program. An ammonia boiler environmental control system was designed to supplement the existing system after the craft descends through 100,000 ft to the time of rescue.

#### **1990-1991 UCF ACRV Design Tasks**

During the 1989-1990 year, the Engineering Design classes examined solutions in support of post landing operations for the ACRV. The 1989 fall semester class selected designs in the areas of: 1) crew egress and rescue personnel support, 2) orientation, attitude control, and stabilization, 3) medical support systems, and 4) crew survival systems. The 1990 spring semester class, with new students, was responsible for providing greater detail to the designs selected in the fall semester. The design requirement was increased in the 1990-1991 academic year from one semester to two semesters. The students participating in conceptual design during the fall semester now continue with building and testing in the spring semester. The task objectives for the 1990-1991 Engineering Design class were to determine the feasibility of the previously developed egress and stabilization systems for deployment on the ACRV. Working models of these systems were designed, built, and tested. The scale selected for the development of these systems was one-fifth. Four design teams were formed and tasked as follows:

#### **Design Team #1 - ACRV Model Construction**

The responsibility of the ACRV Model Construction team is to design, build, and test a one-fifth scale model based on the Apollo Command Module (ACM) such that the egress and stabilization systems can be incorporated and tested. The model is required to



accurately simulate the geometric and dynamic characteristics of the ACM derivative for testing purposes. The model construction effort is presented in Section I of this report.

## **Design Team #2 - Water Test Facility Identification**

The Water Test Facility team was responsible for identifying a test facility where stabilization tests on the ACRV model can be performed. This includes researching existing facilities as well as, establishing designs for a permanent facility at the University of Central Florida. As a result of the investigation, presented in Section II, an existing facility was selected for testing therefore, building and testing phases are not included.

## **Design Team #3 - Rapid Egress Systems**

The objective of the Rapid Egress System team was to design, build, and test the Four Link Injured Personnel Egress Mechanism (FLIPEM) optimized during the previous year. The FLIPEM consists of three parts: the lift mechanism, the extension support mechanism, and the restraint mechanism. The lift mechanism must translate the couch platform from the ACRV floor to the hatch location. The extension support mechanism provides the means to move the couch platform a specified horizontal distance out the hatch for recovery. The restraint mechanisms are required to ensure the FLIPEM remains in the stowed position prior to deployment and to also prevent movement of the couch on the platform during FLIPEM operation. The development and testing of the egress system is presented in Section III of this report.

## **Design Team #4 - Stabilization Control Systems**

The objective of the Stabilization Control Systems team was to determine, through modelling, the feasibility of reducing the motions of the ACRV model on water using an underwater parachute system. The underwater parachute system should stabilize the ACRV out of the range of motion which causes seasickness to prevent further injury or illness. This range is approximately 0.2 - 0.5 Hz. Associated with the underwater parachute system are the attitude ring and mattress. The attitude ring is a buoyancy control device attached to the ACRV to aid in floatation and stabilization. The attitude ring mattress is located under the hatch and acts as a stable platform for recovery operations. The design, building, and testing of the stabilization control systems is presented in Section IV of this report.



## **SECTION I.**

### **ACRV MODEL CONSTRUCTION**

#### **DESIGN PHASE**

- \* CENTER OF GRAVITY AND MASS MOMENT
- \* MOLD AND SHELL MATERIALS
- \* SHELL ATTACHMENT METHODS
- \* SUBSYSTEM VOLUME ALLOTMENTS

#### **BUILDING PHASE**

- \* MODEL CONSTRUCTION
  - PLUG/MOLD
  - SHELL
- \* CENTER OF GRAVITY AND MASS MOMENT

#### **TESTING PHASE**

- \* TEST PLAN
- \* TEST RESULTS



## **SECTION I. ACRV MODEL CONSTRUCTION**

### **INTRODUCTION**

The one-fifth scale working model simulates the dynamic behavior of an Apollo Command Module (ACM) derivative. The physical and dynamic characteristics of the model were established through consultations with Rockwell International/Space Systems Division. Concepts associated with the ACRV Model Construction are presented in the design phase portion of this section. Model construction techniques and schedules are presented in the building phase portion and the test plan and results are detailed in the testing phase portion. General design considerations for the ACRV Model Construction are as follows:

#### **Scaling Factors**

Geometric similarity requires that linear distance be scaled by a factor  $\lambda$  equal to 1/5 (Figure 1.1). The mass of the model must be scaled with respect to volume by  $\lambda^3$  for the model to float at the correct depth in the water. Time is scaled by a factor  $\lambda^{1/2}$ .

#### **Scale Factors for Rigid Body Motion [4]**

Variable	Symbol	Scale Factor	Value
Length	L	$\lambda$	0.2
Acceleration of Gravity	g	1.0	1.0
Mass	M	$\lambda^3$	0.008
Mass Moment of Inertia	J	$\lambda^2$	0.00032
Specific Thrust	P	$\lambda^2$	0.2
Specific Impulse	I	$\lambda^{3/2}$	0.08944
Time	t	$\lambda^{1/2}$	0.4472
Displacement	X	$\lambda$	0.2
Linear Velocity	V	$\lambda^{1/2}$	0.4472
Linear Acceleration	a	1.0	1.0
Angular Rotation	$\theta$	1.0	1.0
Angular Velocity	$\omega$	$1/\lambda^{1/2}$	2.236
Angular Acceleration	$\alpha$	$1/\lambda$	5.0

# GEOMETRIC SIMILARITY

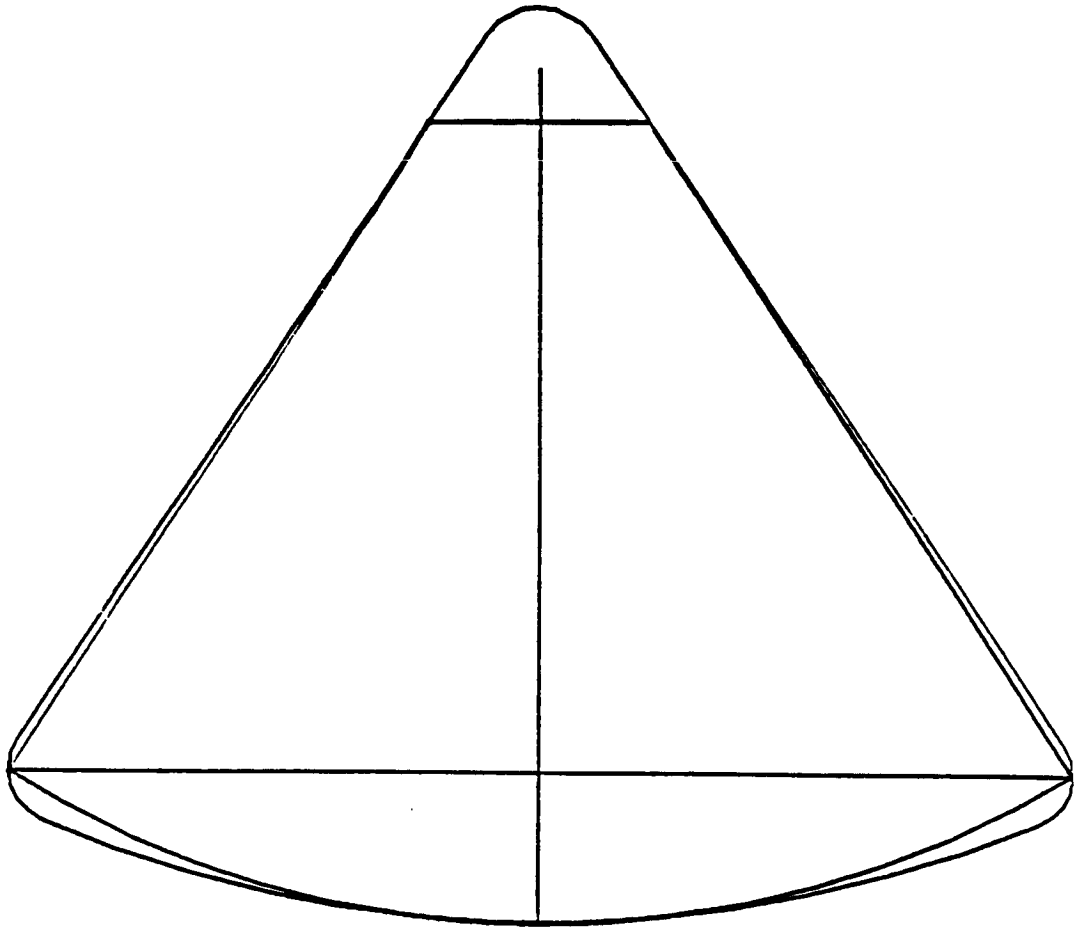


FIGURE 1.1

## **Center of Gravity and Mass Moment**

To model the CG and mass moment of inertia, it is necessary to construct a subsystem capable of easily varying the position of the CG and the magnitude of the mass moment of inertia independently. Methods of accomplishing this variability include a concentrated mass at the CG, a peripheral weighting system, a weight on a vertical rod, and a circular flat plate. These methods are compared and contrasted with respect to their effectiveness and ease of variability.

## **Construction Materials**

Materials under consideration include wood, aluminum, plastic polymer, and fiberglass. Material selection factors discussed include rigidity, strength, durability, weight, and ease of construction.

## **Shell Attachment and Interior Accessibility**

The interior components must be easily accessible from the outside by means of splitting the shell along a horizontal plane. Methods of attaching the two halves of the model include dowel pins and latches, magnets, and plates and pins. The advantages and disadvantages of these methods are discussed in terms of alignment, rigidity, strength, and water proofing.

## **DESIGN PHASE - ACRV MODEL CONSTRUCTION**

Various design alternatives were conceived. These designs vary in form and provide a variety of solutions to the problems encountered. Integration meetings and briefings were held with NASA/KSC, Rockwell/SSD, and Air Force Astronaut Recovery personnel throughout the academic year to ensure the fidelity and acceptance of the ACRV model.

## **Chapter 1.0 CENTER OF GRAVITY AND MASS MOMENT**

To provide a stability analysis during water tests, it is necessary to vary the center of gravity and mass moments of inertia within a working envelope of possible configurations. The mass moment of inertia is a statistical measure describing the resistance of an object to rotation about an axis. It is a function of the distribution of mass about that axis, or more specifically, a function of the radius of gyration. Therefore, to vary the mass moments of the model, the distribution of mass about the axes of rotation is varied within the constraints of the required magnitude and location of the center of gravity [5]. The stabilization tests using the ACRV model measure pitch, yaw, and heave motions. Pitch is rotation about the

horizontal Y axis, yaw is rotation about the horizontal Z axis, and heave is translation through the vertical X axis.

Nonhomogeneities and asymmetry of the constructed shell require empirical determination of the exact values of the weight, CG, and mass moment of inertia. The mass is measured by weighing the model on a scale. The location of the CG and the magnitude of the mass moments of inertia are then measured by suspending the model from a wire and measuring the period of oscillation as it is swung pendulum-like from the top and then from the bottom of the model. Any addition of weight requires calculation of new positions of CG and mass moments with respect to these initial values.

The data from the experiment is used to calculate the actual CG and mass moment of inertia of the model. There are two unknowns to be solved;  $L$ , the distance from the top of the shell of the model to the CG, and  $I_G$ , the mass moment of inertia of the model about the CG.

Hang the model from its top by a 1 foot wire:

$$(\tau_1)^2 = \left(\frac{4\pi^2}{mg}\right) \frac{(I_G + m(1 + L)^2)}{1 + L}$$

Hang the model from its bottom by a 1 foot wire:

$$(\tau_2)^2 = \left(\frac{4\pi^2}{mg}\right) \frac{(I_G + m(3.2-L)^2)}{3.2 - L}$$

where  $\tau_1$  and  $\tau_2$  are the periods obtained from the pendulum test. Rearranging the two equations and subtracting results in the following solutions:

$$\text{letting } k = \frac{mg}{4\pi^2}$$

$$L = \frac{-9.24m + k(3.2(\tau_2)^2 - (\tau_1)^2)}{8.4m - k((\tau_1)^2 + (\tau_2)^2)}$$



$$I_G = -mL^2 + L(k(\tau_1)^2 - 2m) + k(\tau_1)^2 - m$$

### 1.1 Concentrated Mass

A simple means of positioning the CG is to place a concentrated mass at the required location. A possible method of varying the location of the mass is to secure it to a pegboard fixed to the interior base of the model parallel to the YZ plane either above or below the CG plane. The horizontal location of the CG is varied by the selection of different holes in the pegboard. The vertical position is varied by using spacers between the pegboard and weight. This method provides variation of the CG location, but would require excessive weight to achieve the necessary mass moment.

### 1.2 Peripheral Weights

To obtain the desired mass moment without exceeding weight requirements, the radius of gyration must be increased. A peripheral weighting system provides an increase in the radius of gyration. Proper location of weights on the interior surface of the shell make it possible to model both the CG and the mass moment. By varying the magnitude and location of the weights, the CG and the mass moment are changed. This method has two disadvantages. First, the weight, mass moment, and CG are mutually dependent making it difficult to vary only one parameter. Second, the mass moment, and therefore the angular acceleration, varies with the axis of rotation through the horizontal YZ plane due to the asymmetry of the weights.

### 1.3 Mass on Vertical Rod

A means of increasing the radius of gyration while reducing the degrees of freedom is to combine a concentrated mass on a pegboard near the CG with a movable weight attached to a vertical rod on the X axis centerline of the model (Figure 1.2). The vertical position of the CG is varied by balancing the masses and positions of the weights with respect to the required position. The pegboard weight provides adjustment of the horizontal position, while the combination of weights provides a sufficient radius of gyration for the mass moment. This method has three disadvantages. First, the vertical rod must be rigidly fixed to the top and bottom of the model. This configuration compromises the ability to split the model horizontally for access to the interior. Second, the close proximity of the CG to the base of the model reduces the ability to compensate for a large weight on the rod near the top of the vehicle. This proximity limits the radius of gyration that the model can provide. Third, a vertical rod in the center of the model reduces the available volume for other required subsystems.

## MASS ON VERTICAL ROD

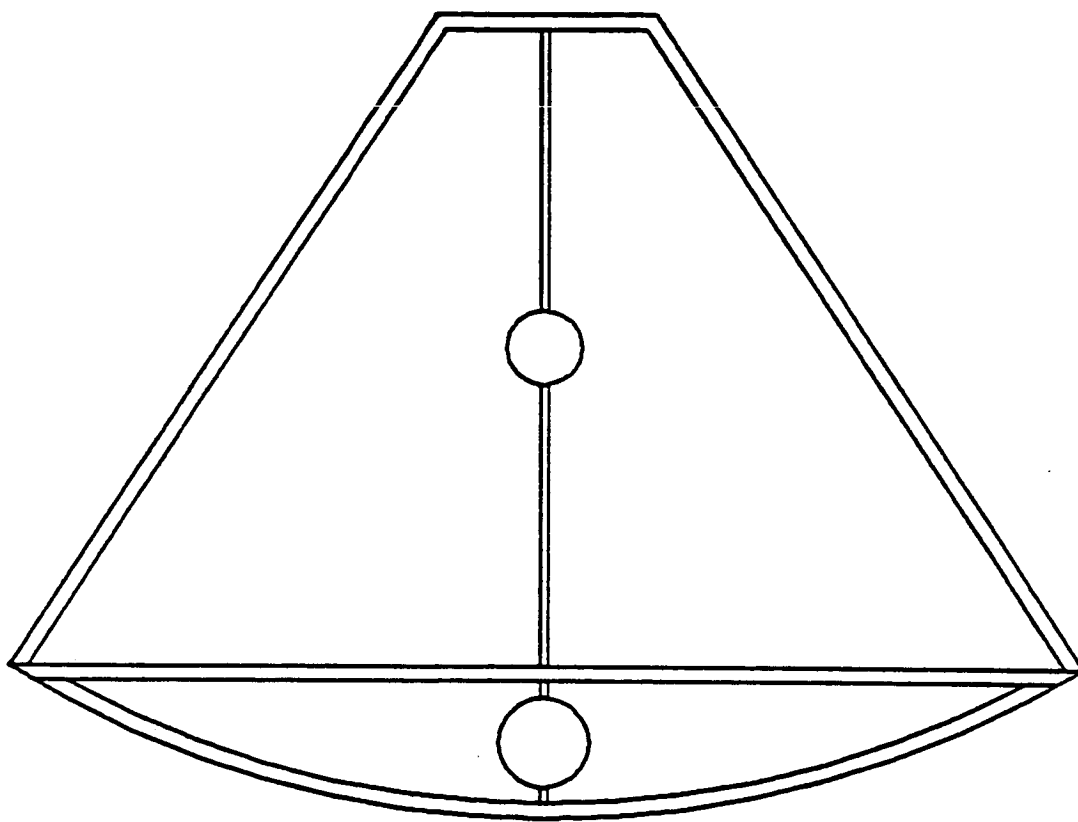


FIGURE 1.2

## 1.4 Flat Circular Plate

To overcome the limitations imposed by distributing the weight vertically, it is feasible to distribute the weight horizontally. A flat, thin plate mounted to a horizontal pegboard provides adjustability of the CG both vertically and horizontally by the use of holes and spacers (Figure 1.3). The mass moment varies negligibly as the CG is moved if the mass of the plate is large compared to the mass of the shell, reducing the interdependence of the parameters. A circular plate provides a uniform mass moment about any horizontal axis through the CG. This uniformity reduces inconsistencies in testing due to the attitude of the model. A disadvantage is that the plate must be shaped like a washer to reduce the required mass. To obtain the washer shape machining of a steel plate is necessary.

## Chapter 2.0 CONSTRUCTION MATERIALS

The position of the center of gravity (CG) and the magnitude of the mass moment of inertia of the model are dictated by the requirement of geometric similarity to the Apollo Command Module (ACM). During water tests, plans are to measure the effect of varying the CG and mass moment on the stabilization system by means of a variable CG/Inertial subsystem. The contribution of the shell mass must be minimized to increase the sensitivity of the system to changes in the variable subsystem.

### 2.1 Plywood

The first material considered for the ACRV model construction was plywood. The plywood construction process consists of three phases. First, the bottom shell is built. Next, the upper shell is constructed with appropriate interior supports. Finally, the two shells are attached and sealed.

Construction phase 1 involves cutting semicircular sections of plywood. These semicircles are then attached perpendicular to a round base to form a hemispherical bottom surface. Foam insulation is inserted between the supports for strength and buoyancy. Finally, the foam is shaped to maintain the curved surface.

Construction phase 2, the upper shell construction, involves assembling and securing the plywood plates that form the upper shell. To provide the conical shape, the shell consists of eight panels that are supported internally. This internal support consists of two attached sections of plywood (Figure 1.4).

## FLAT CIRCULAR PLATES

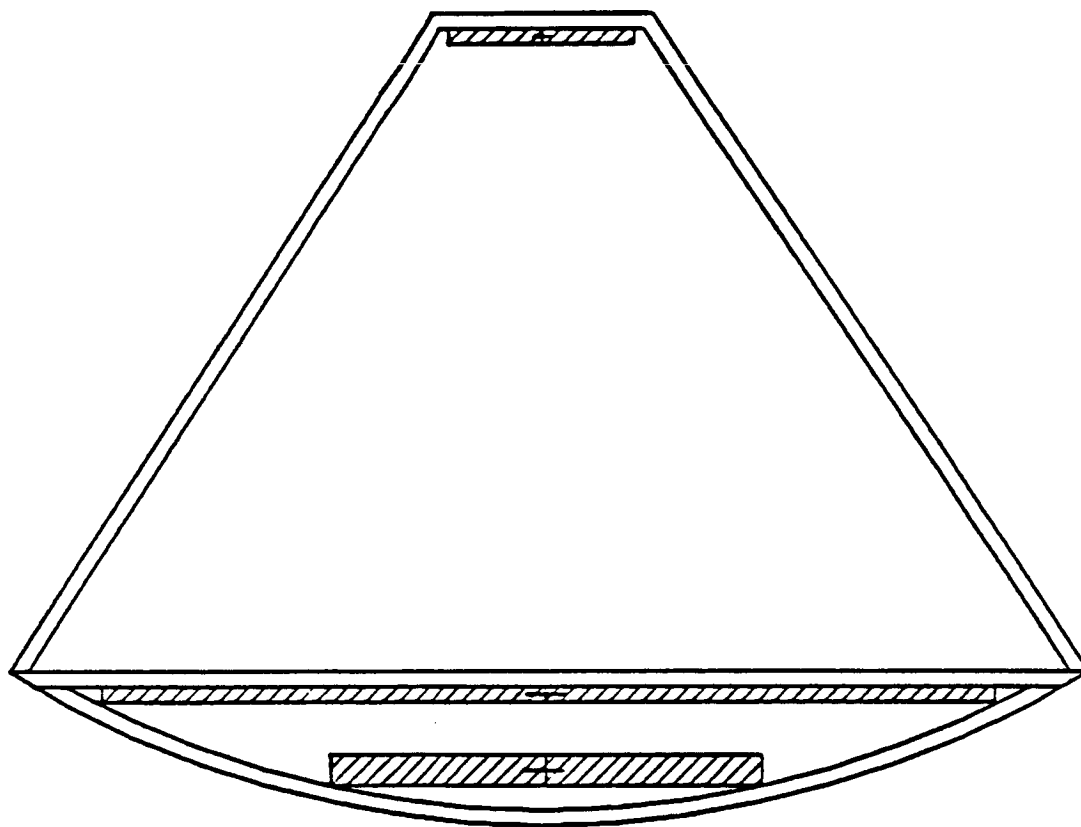


FIGURE 1.3

## PLYWOOD/ALUMINUM INFRASTRUCTURE

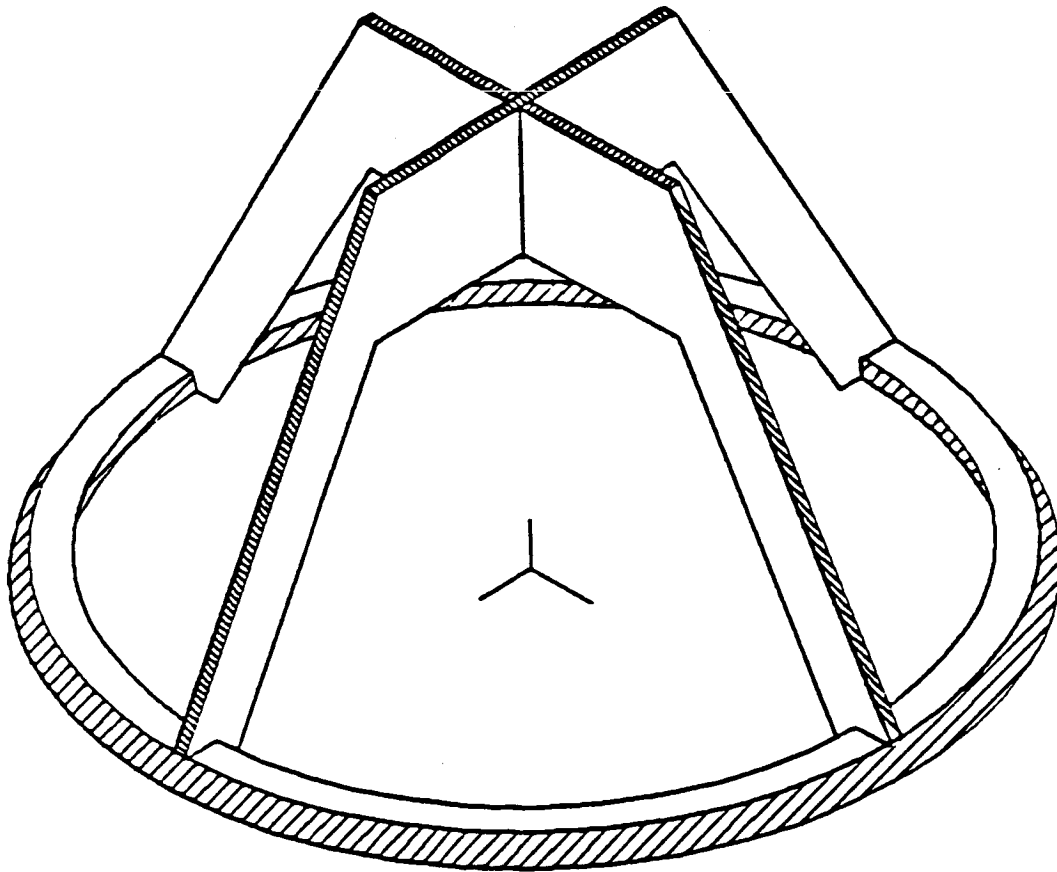


FIGURE 1.4

The main advantage of plywood is availability. Another advantage is that a plywood model can be easily repaired. If a plywood panel were damaged, it would be detached and replaced. Plywood also offers strength. It is strong and stiff along the grain. Careful attention will insure the long axis of each cut is with the grain. A final advantage is its adaptability. The strength of plywood provides freedom to attach stabilizing mechanisms at any location on the model. [6]

Plywood has several disadvantages. The major disadvantage is buoyancy. A model made of plywood does not provide adequate floatation. To increase buoyancy, foam insulation must be added, but foam reduces the amount of free space in the bottom shell. Another disadvantage is that plywood tends to absorb water, so it must be extensively waterproofed. Also, the seams between panels need to be sealed against water intrusion. The necessity of an infrastructure for the top shell is a disadvantage. The infrastructure consumes internal space used to accommodate the stabilization and rapid egress systems.

## 2.2 Aluminum

Aluminum is being considered as a construction material. A first step, when constructing a model made of aluminum, is to build a wood frame similar to the one used for wood construction. The aluminum is then bent around the wood frame. The top and bottom halves are built in this manner and any seams are welded.

An aluminum model offers several advantages. The main advantage is the ability to imitate the shape of the ACRV. Aluminum can be bent to form the hemispherical shape for the bottom shell and a conical shape for the top shell. In addition, an aluminum model requires no waterproofing. The welded seams prevent leakage. Finally, a model made of aluminum provides adequate floatation without the addition of buoyancy increasing materials.

An aluminum model has several disadvantages. One disadvantage is the need of an infrastructure. An infrastructure, similar to the one required for a wood model (Figure 1.4), is needed to support external attachments. Another disadvantage is that aluminum is difficult to repair and maintain. Major structural damage would have to be repaired by welding. Finally, aluminum is easily deformed. The conical shape could be compromised, thus distorting the dynamic modeling characteristics.

## 2.3 Plastics

The plastic polymer being considered involves constructing a mold of the ACRV that is the shape of the outside of the vehicle. The plastic, in a flexible sheet, is "stretched" over the mold, allowed to cool, and the mold is then pulled away.

Advantages of plastics are its low density and waterproof characteristics. Plastic can also be formed into any shape, such as the shape of the ACRV. Finally, plastic has the high strength-to-weight ratio needed to support external attachments.

A disadvantage to plastic is that it is difficult to repair. Repairs require labor intensive patching. Also of concern is the integrity of the shape. Dents can be created and are difficult to repair.

## 2.4 Fiberglass Composite

Another material being considered for the construction of the ACRV model is a composite sandwich of S-fiberglass (S-glass) and resin laid on both sides of a sheet of closed-cell PVC foam. The foam has lateral and vertical grooves cut into each sheet. These grooves allow the sheet to be bent into complex curves allowing smooth curves for both the top and bottom sections of the model. The advantages of this material include light weight, stiffness, durability, ease of repair and modification without the need for a supporting inner structure (Figure 1.5).

Sandwich construction is comparable to I-beam construction due to the distance of the load-carrying material from the neutral axis. The distance of the load-carrying material from the neutral axis increases the area moment of inertia and therefore the stiffness of the shell. By reducing the compliance of the shell, momentum is transmitted directly to the CG. This reduced compliance permits the assumption that the shell is a rigid body and simplifies dynamic calculations.

The durability of fiberglass/resin composites is an advantage for use in water environment. The composites are fatigue resistant and absorb impact energy that would dent or puncture other materials. If closed-cell PVC foam is used, the composite structure is watertight and will not absorb water or suffer loss of strength from water contact.

Fiberglass is easy to repair or modify. Broken parts can be cut out and new parts attached in a short time period. The grooves in the foam create a pattern of squares on the surface which provide a template for cutting and replacing sections of the shell. Small repairs can be performed with 5-minute epoxy, and larger repairs with polyester resin. The repairs are watertight and require no extra sealing. Additions to the structure can be glassed onto the existing structure with a minimum of surface preparation.

An advantage of the composite shell is the lack of need for an internal structure. This provides the maximum volume possible for the egress system, stabilization system, and any measuring equipment necessary for testing. However, a reinforcing infrastructure will be necessary for the egress and stabilization systems.

# FIBERGLASS COMPOSITE SHELL

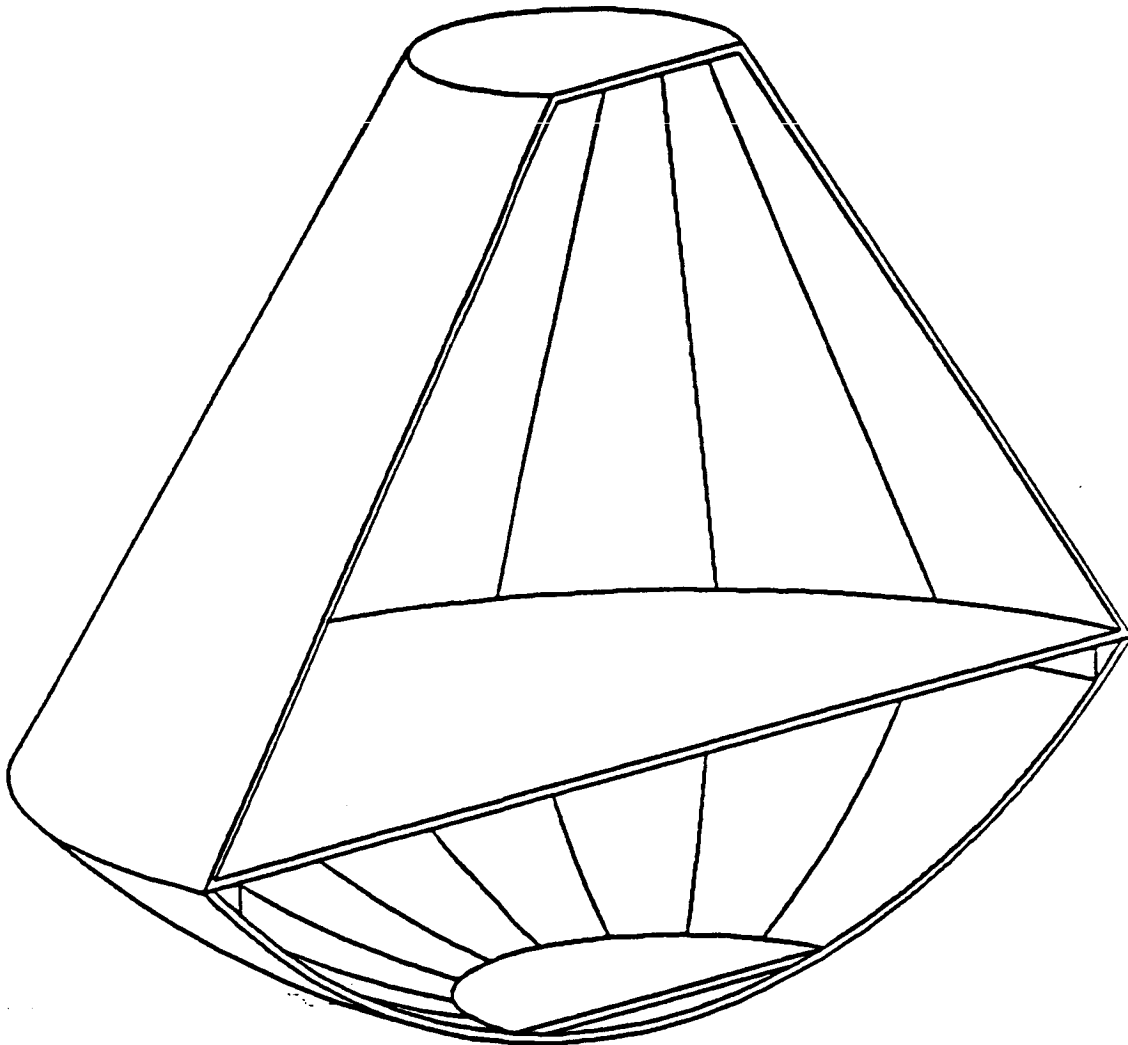


FIGURE 1.5



Disadvantages of the fiberglass shell are related to construction methods. Construction requires building a mold before laying up the glass and foam. This is a labor intensive task, but once the mold is built, shells can be made easily. The fiberglass skin is strong in tension and bending, but weak in shear. This requires the addition of reinforcing hard points at locations where bolts or other fasteners penetrate the skin for attachment. Although the hard points are quite strong, they add to the time required for construction of the shell.

## **Chapter 3.0 METHODS OF ATTACHMENT**

The ACRV model consists of two parts: the top and bottom shells. A method must be devised to attach the parts. For a method to be viable, it must meet several requirements. First, the method of attachment must combine the parts to form a rigid body. This rigidity is necessary to prevent unwanted vibrations during testing. Also, the attachment must properly align the two parts and provide the strength to support the bottom half of the model. The method of attachment must be compatible with the material used to build the model. Finally, the attachment method must make the breakline watertight, since various types of equipment will be placed inside the model. Each method of attachment has been evaluated according to these criteria.

### **3.1 Dowel Pins and Latches**

A dowel pin and latch type attachment (Figure 1.6) is simple to manufacture. This attachment method consists of dowel pins to provide alignment and latches to provide support. The dowel pins are permanently attached to the top part of the model. Corresponding holes are drilled into the bottom part. When the parts are attached, the pins correctly align the model. The latches are placed on the outside of the model. When the parts are together, the latches are secured to provide support. The final component in this method is a rubber gasket between the two parts. This gasket prevents water from leaking in at the model break-line.

This method of attachment has many advantages. Dowel pins provide rigidity and assure alignment. This is a major advantage since the two parts must move as one unit. The latches are simple and dependable and they also provide strength to support the bottom part of the model.

This method has some disadvantages. One, is that holes for the dowels must be placed in the gasket. These holes reduce the efficiency of the gasket. To accommodate dowel pins, the shell thickness must be greater than the dowel diameter. Obtaining the proper thickness may be a problem depending on the model material. Another disadvantage is that the latches must be on the exterior of the model. The latches detract from the appearance of the model.

## DOWEL PINS AND LATCHES

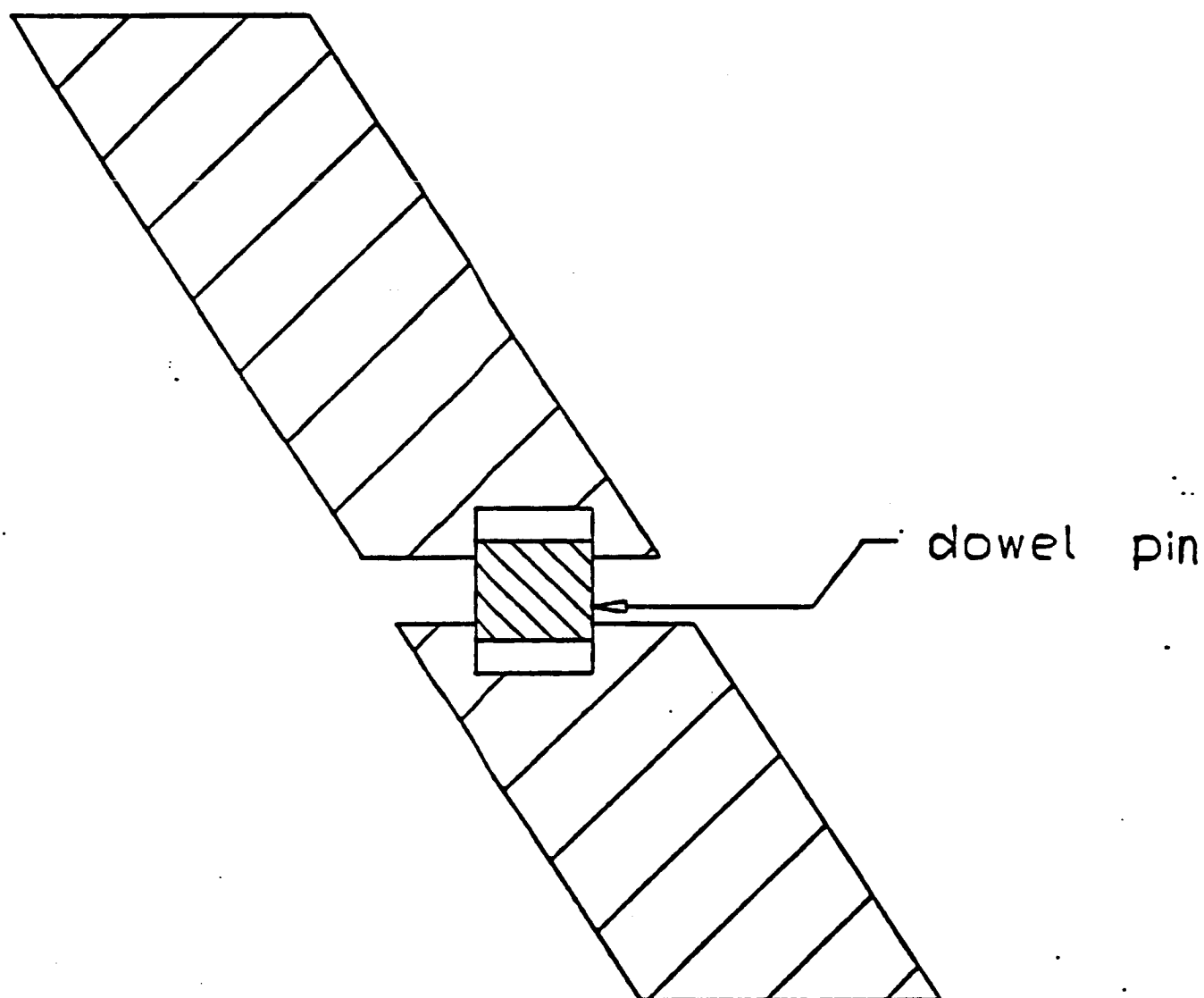


FIGURE 1.6

### 3.2 Magnets

Magnets may be used as a method of attaching the upper and lower parts (Figure 1.7). When the two parts are together, the attraction of the magnets provides support and alignment. A gasket is used to keep water out of the model.

The use of magnets is appealing since it combines support and alignment in one unit. It offers the advantages of being hidden from sight and not marring the appearance of the model. Finally, magnets can attract through the gasket material, therefore they will not interfere with the gasket.

The use of magnets has several disadvantages. The first disadvantage is availability. The magnets must be small enough to fit in the shell and strong enough to support the bottom half of the model. Another disadvantage is that if natural magnets are used, detaching the model halves may be difficult. If electromagnets are used, a power source is needed to turn the magnets on and off.

### 3.3 Plates and Pins

The plates and pins method of attachment (Figure 1.8) consists of several plates with pins positioned through the plates. These plates are permanently attached to the top half of the model, and extend several inches below the breakline. A hole drilled through the extending part of the plate corresponds with a hole in the bottom half of the model. When the two parts are together, a pin placed through the hole secures the two parts. This method requires a gasket for water sealing.

This method of attachment offers many advantages. Alignment and support are a particular advantage. This unit could be made out of a thin steel plate, offering the advantage of not detracting from the appearance of the model. This method also offers the advantage of not requiring a thick shell because the steel plate can be attached to a thick or thin shell wall. In addition, this attachment does not interfere with the gasket.

The disadvantages of this method concern the pins used to secure the two parts. Complications may arise in keeping the pins in the holes. When the model is undergoing testing the pins may vibrate out of the holes. Another problem may arise concerning the strength of the pins. These pins are subjected to a shearing stress due to the weight of the bottom part of the model. This shearing stress may cause pin failure.

# MAGNETS

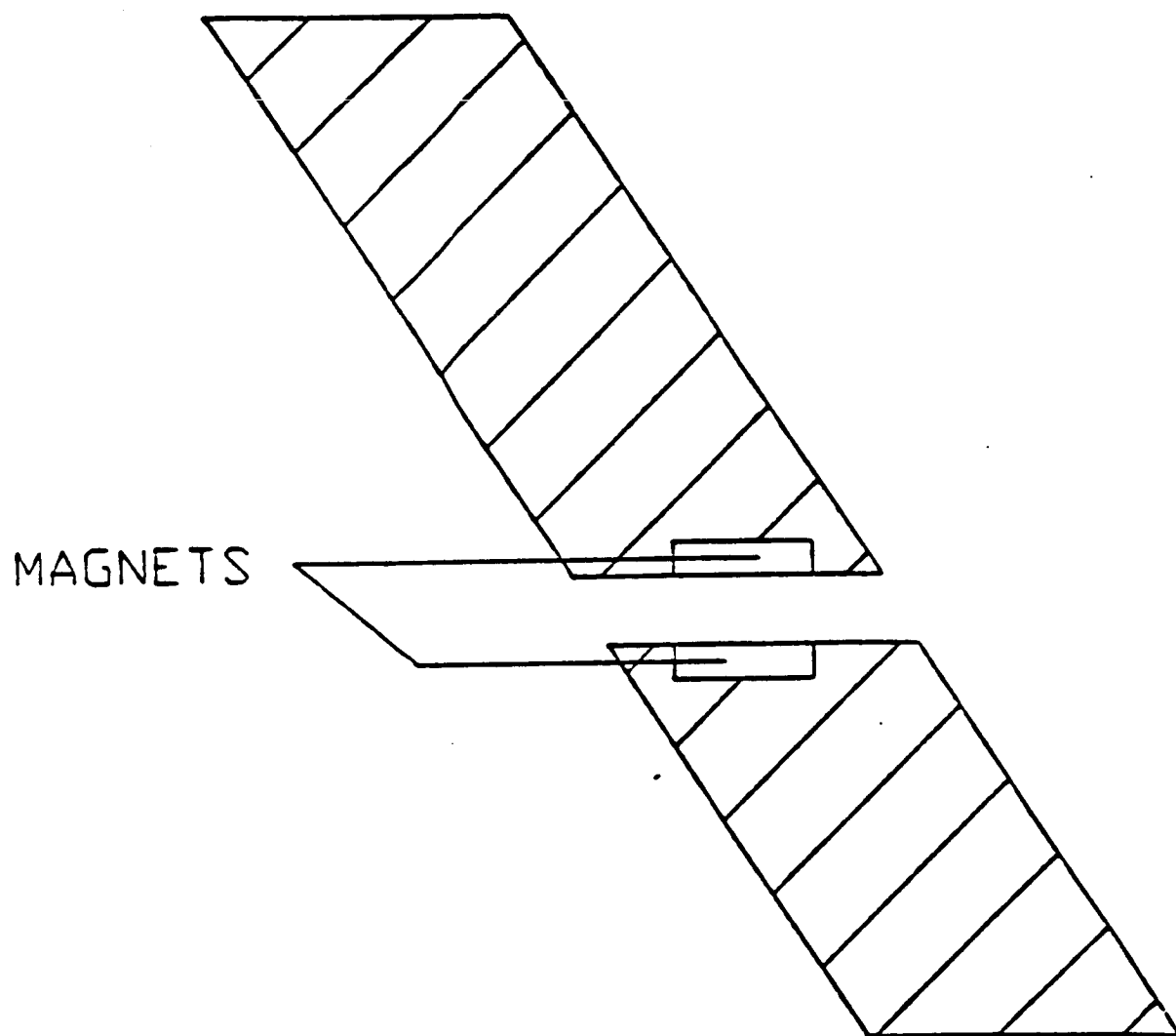


FIGURE 1.7

## PLATES AND PINS

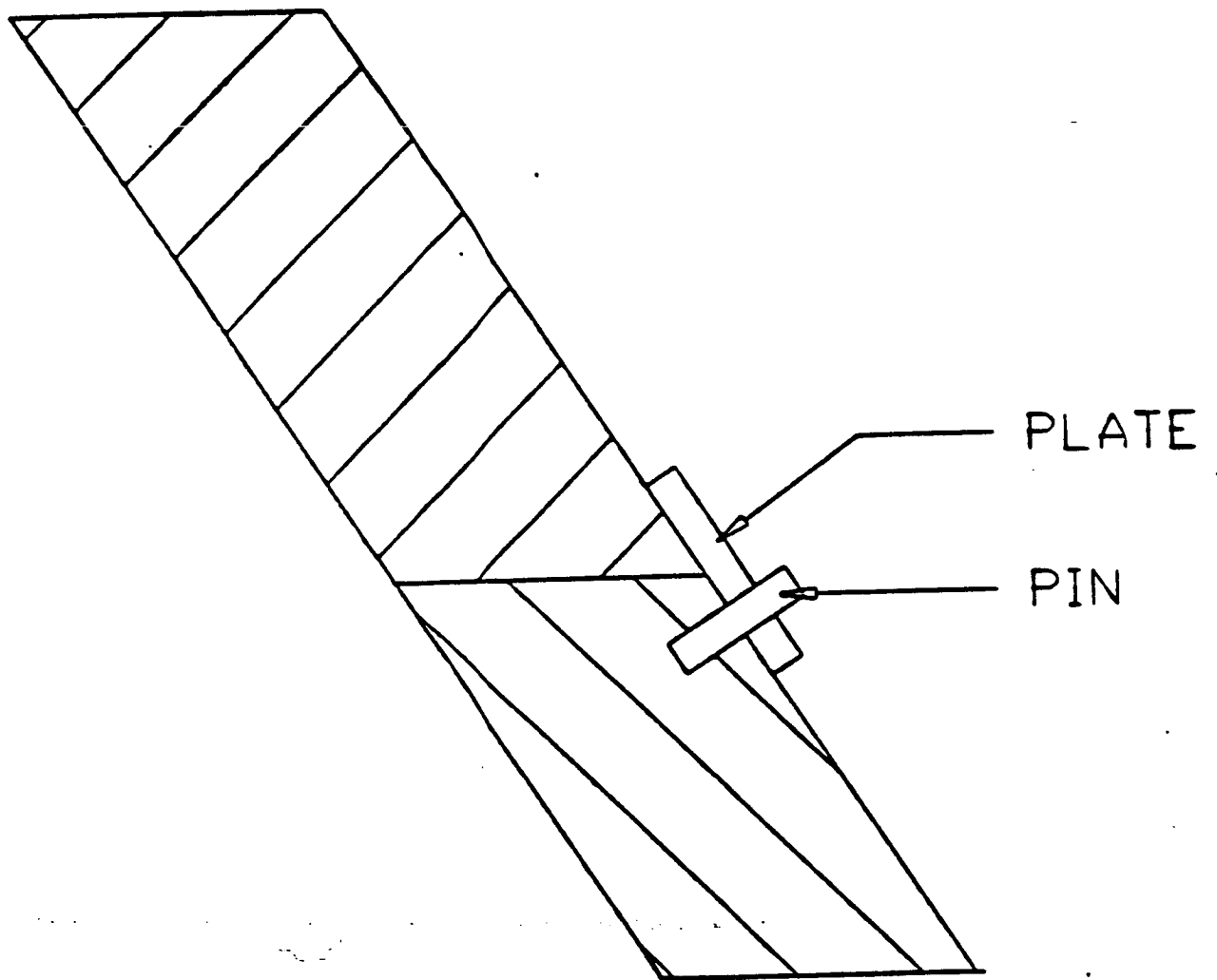


FIGURE 1.8

## **Chapter 4.0 SUBSYSTEM VOLUME ALLOTMENTS**

The ACRV model must provide volume and means of attachment for the egress and stabilization systems. The egress system requires volume for the lifting mechanism and the egress couch, as well as a means of firmly attaching the lifting mechanism to the model. The stabilization system requires volume and attachment for three seismic accelerometers, three shock accelerometers, and an amplifier. A hole must be provided in the model to accommodate the wires for the data acquisition system.

The upper shell of the ACRV model is hollow and provides a large volume for the egress system. The floor of the shell is a fiberglass sandwich construction to provide rigidity for the couch. Hardpoints will be provided at locations to be determined by the egress systems design team. A second upper shell was produced to include a hatch. Hatch location and the required stabilizing forces for the couch was determined by the egress team. Hardpoints at the hinges and other required locations on the hatch or shell are provided.

The stabilization testing subsystem requires volume for accelerometers and an amplifier. Hardpoints are provided at the required locations. The amplifier was mounted low in the shell on the floor of the model. Hardpoints provide a rigid mount for the amplifier to the plywood floor. A wiring harness was routed through a hole in the shell near the top of the model. A hole with a rubber grommet for protection of the cable was provided at the required location.

## **Chapter 5.0 OPTIMAL SOLUTION - ACRV MODEL CONSTRUCTION**

### **5.1 CG/Mass Moment System**

This section presents the chosen optimal design for the ACRV Model Construction effort. Chosen alternatives are presented in this section, including the criteria on which the decisions were based. Decision matrices 1.1 - 1.3 (Appendix H) were formulated to aid in the decisions.

To provide the model with the correct CG and mass moment of inertia, it is necessary to construct a subsystem to vary the position of the CG and the magnitude of the mass moment of inertia independently. Alternatives for fulfilling this requirement include a concentrated mass at the CG, a peripheral weighting system, a weight on a vertical rod, and a circular flat plate. The alternatives evolved in a logical progression from only fulfilling the weight and CG requirements to providing the proper mass moment of inertia.

A system of three flat circular plates was chosen for modeling both the CG and mass moment of inertia of the ACRV. This system consists of a fixed flat plate mounted inside the top of the shell, a second fixed plate at the bottom of the base of the shell, and a

movable plate at the floor of the model. The system of three flat circular plates can be treated as a concentrated mass with local CG at the centroid of the plates. By varying the position of the center plate, the CG of the model can be altered for testing. The peripheral weighting and the weight on a rod are capable of modeling the CG of the ACRV, but are more complicated to adjust than the flat plates.

The flat circular plates also contribute the necessary mass moment of inertia to the shell. The mass moment of a flat circular plate about a diameter is easily calculated. Given the parameters of weight, mass moment, thickness, and radius, suitable plates can be cut. A range of mass moments and weights can be modeled by machining a series of plates of the proper dimensions.

The peripheral weighting and the weight on a rod designs are capable of modeling the CG and mass moment of inertia. However, they introduce complications that compromise ease of varying parameters. Both require movement of more than one weight at a time and movement of the CG can significantly alter the mass moment.

Complete analysis of the stabilization subsystem requires testing a variety of CG configurations. The ACRV one-fifth scale model fulfills this requirement by allowing variability of position of the middle flat circular plate. This plate is bolted to the floor of the ACRV model using a system of four studs, spacers and washers. The plate has seven sets of stud holes with an offset ranging from zero to 1.5 inches from center to either side in increments of 0.5 inches. A series of spacers on the studs allows vertical variation of the plate. The floor can be flipped 180 degrees to permit a vertical range of approximately 6 inches. (Figure 1.9)

## 5.2 Construction Materials

The construction material for the ACRV model had to meet several requirements. The chosen material had to be easy to work with and repair. It also had to be strong and stiff, watertight, and light weight. The materials considered were plywood, aluminum, plastic, and fiberglass composite. The optimal material chosen is fiberglass.

Fiberglass is easy to work with and simple to repair. The materials needed for building and repair can be obtained from local supply stores. Plywood and aluminum are also easy to obtain, but are difficult to work with and repair. Plastic construction materials are difficult to work with and are not readily available.

Fiberglass meets the strength and stiffness requirements of the design. Plastic also meets these requirements. Plywood and aluminum models need an infrastructure to provide the required strength and stiffness. The additional weight of an infrastructure is a disadvantage.

## VARIABLE CG CENTER PLATE

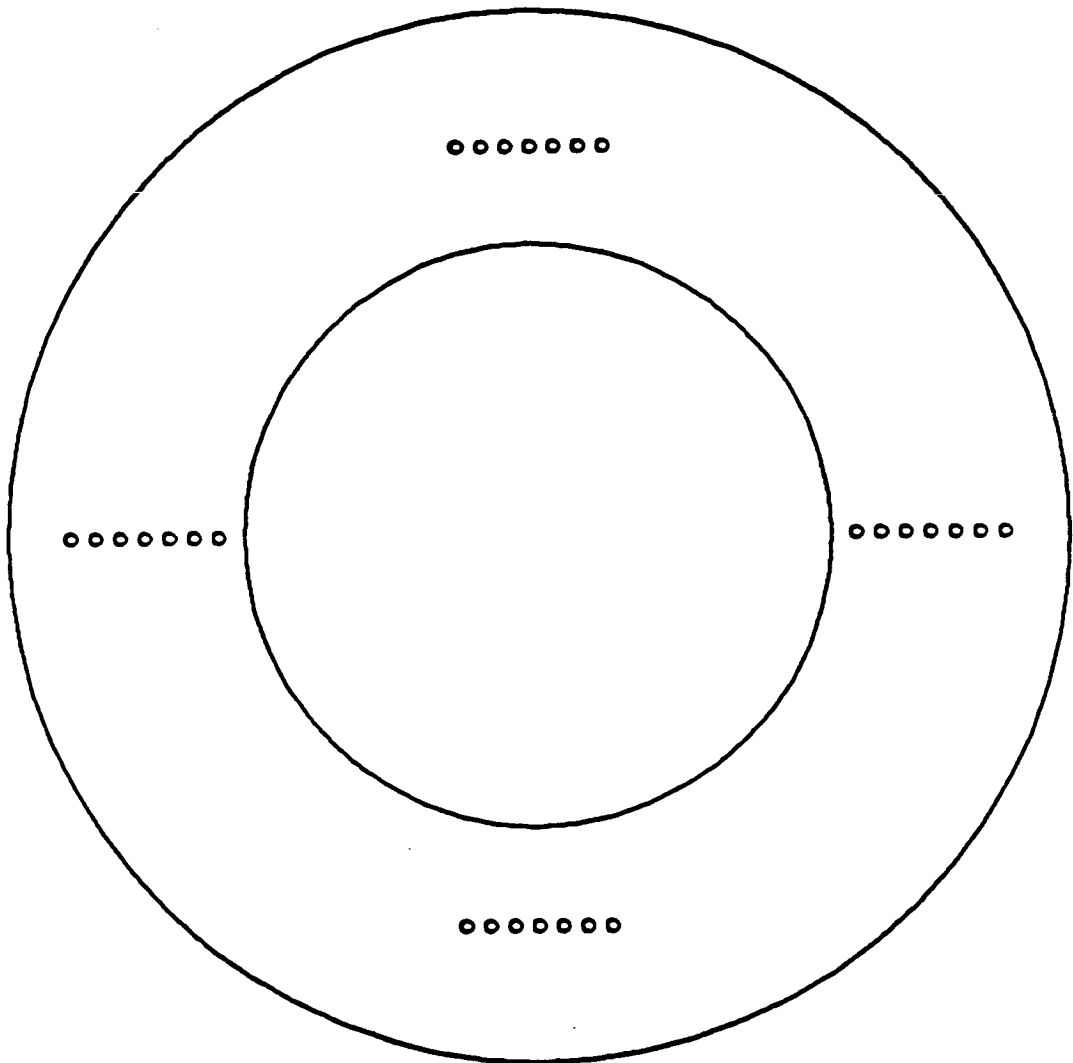


FIGURE 1.9



Another requirement is that the construction material be waterproof. A fiberglass model is completely waterproof due to the resin coating. A plastic model is also waterproof. Plywood has a tendency to absorb water, therefore requiring waterproofing material. Waterproofing an aluminum model requires accurate welding of the seams to insure against water intrusion.

Finally, it is important that the construction material be lightweight. Fiberglass is lighter than plywood and aluminum. Fiberglass becomes heavier when hardpoints are added, however even with hardpoints a fiberglass model is lighter than aluminum or plywood models.

### **5.3 Method of Attachment**

The subsystems and equipment contained within the model must be easily accessible. The model separates into two parts and a method of attachment has been designed. The chosen design for the method of attachment for the ACRV model has to meet several requirements. The attachment design needs to securely fasten the upper and lower shells to form a rigid body. Second, the design must align the upper and lower shells correctly. Third, the design needs to be strong to hold the two shells together in addition to enduring a large shock load from the stabilization system. Finally, the design must be compatible with the chosen construction material.

The designs considered were dowel pins and latches, plates and pins, and magnets. The optimal solution is plates and pins.

The plates and pins design securely fastens the upper and lower shells to form a rigid body. There is no horizontal or vertical movement once the securing pin is in place. This lack of movement enables the ACRV model to be treated as a rigid body for mathematical modeling.

The next requirement is that the attachment design align the top and bottom sections accurately. The plates and pins enable the top and bottom to be aligned and assembled in one configuration. Hatch alignment is crucial to the egress tests. If magnets were used, alignment would be difficult.

Strength in the attachment design is a consideration. The majority of the model weight is in the bottom shell requiring the design to secure up to 120 pounds of lower shell weight. A second load on the plates and pins is the stabilization system. Shock loads, up to 200 pounds, may act upon the stabilizing pin (eye hook) during stabilization testing. The magnet size required to meet these two tasks would not easily fit into the model. Plates and pins accomplish both tasks in a simple, compact design.

The final attachment design requirement is material compatibility. The chosen material, fiberglass, need only be drilled to accommodate the supporting plate. Both dowel pins/latches and magnets require complicated construction procedures. Only the addition of appropriate hard points need be considered when using the plates and pins attachment, which is required of all methods.

## Chapter 6.0 OBSERVATIONS AND RECOMMENDATIONS

Several tasks remain incomplete. First, the center of gravity and the mass moment of inertia of the model must be empirically determined. Second, the actual hatch location must be determined. Third, a decision whether to sub-contract the shell construction or construct the shell independently must be made. Finally, the ability of the model to withstand shock loading must be tested.

The actual size of the inertia plates will be determined after the model is constructed. The model will be weighed and the moment of inertia will be calculated. Although these values have been estimated, they must be experimentally measured for use in testing. A series of plates can then be machined to simulate the desired range of CG and mass moment.

The location on the model for the egress hatch has yet to be determined. Upon determination of the egress hatch location, a shell will be laid up and a hatch provided. Reinforcing hard points will provide strength to support the hatch when the couch is extended.

The third project left to be completed deals with the construction of the model. Costs are estimated to be \$1200 for a mold and \$450 for a shell if sub-contracted. If the mold and shell are built at UCF, the procedure would be time consuming, but the cost would be minimal. A drawback to building the model at UCF is the lack of expertise and potential for error.

A shock load of up to 200 pounds per hook is anticipated due to underwater parachute deployment. This impulsive loading may fracture the hard points. The fiberglass shell will be tested against this loading since the model material will fail before the hooks. An equivalent loading can be simulated by a static loading of the estimated impulsive force at each hook location. Additional tests would involve fatigue loading for an as yet undetermined number of cycles.

## **BUILDING PHASE - ACRV MODEL CONSTRUCTION**

### **Chapter 7.0 MODEL CONSTRUCTION**

Construction techniques used to develop the mold and shell are detailed below. Refer to Figures 1.16 - 1.17 for a description of the work schedules and milestone charts for the mold and shell construction.

#### **7.1 Mold Construction**

The S-glass shell of the ACRV must be formed around a mold. The mold will be used for the initial construction of the two part ACRV model, as well as for additional models that may be needed in case of damage or changes to the vehicle.

The two part mold must be strong to support the construction of the S-glass model and durable to withstand repetitive use. Construction of the mold is crucial to the development of a correct one-fifth scale model of the ACRV. The mold must be downsized from the size of the model to allow for the 0.5 inch thickness of the S-glass composite.

Although the mold is an important part in the model construction process, its cost need not be excessive. The mold for the ACRV has been designed at a relatively low cost by using the following materials:

- 1/2 inch thick wood sheets
- 1/4 inch strips of balsa wood
- Sheets of plywood paneling
- 1/8 inch thick plywood sheets
- 2 inch thick foam sheets
- wood glue
- wood pins

Since the construction of the two part mold is important, a preliminary step by step construction process has been presented for both the top and bottom of the mold.

#### **UPPER SHELL**

##### **Step 1**

Cut two circular plates from the half inch wood sheets for the top and bottom of the upper shell.

The top plate has a 6.2 inch diameter.

The bottom plate has a 33.8 inch diameter.

### Step 2

Cut eight 24.9 inches long strips of balsa wood.

### Step 3

Make eight equidistant marks around the circumference of the top and bottom plates and cut a 1/4 inch deep groove into the plates at each mark. (The balsa wood strips will be angled into the grooves).

### Step 4

Glue the balsa wood strips into the grooves in the top plate and the corresponding grooves in the bottom plate. (If extra reinforcement is needed, use wood pins to secure the ends of the balsa wood strips into the grooves).

### Step 5

Cut two sections of plywood paneling according to the pattern shown in Figure 1.10.

### Step 6

Wrap one section of paneling around the balsa wood and plate configuration in a conical fashion and nail it in place around the top and bottom of the plate section. Repeat this process with the other section of paneling.

### Step 7

The infrastructure of the top shell should resemble Figure 1.11.

## LOWER BOWL

### Step 1

Cut a 33.8 inch diameter plate from the 1/8 inch plywood sheet. This plate is the top of the lower bowl.

### Step 2

Draw full scale cross-section templates

- Cut out paper templates and use them as the pattern to cut 1/8 inch plywood sections and foam sections.
- There will be 16 sections of plywood and foam.
- The sections come in geometrically equal pairs (Figure 1.12).

### Step 3

Assemble the wood and foam sections in an alternating (wood/foam, wood/foam) pattern starting at the center of the plywood sheet with the center sections. These sections make the rough outline of the lower bowl. Glue wood and foam sections together.

### Step 4

Shape rough outline by sanding finished foam piece.

## PLYWOOD PANELING PATTERN

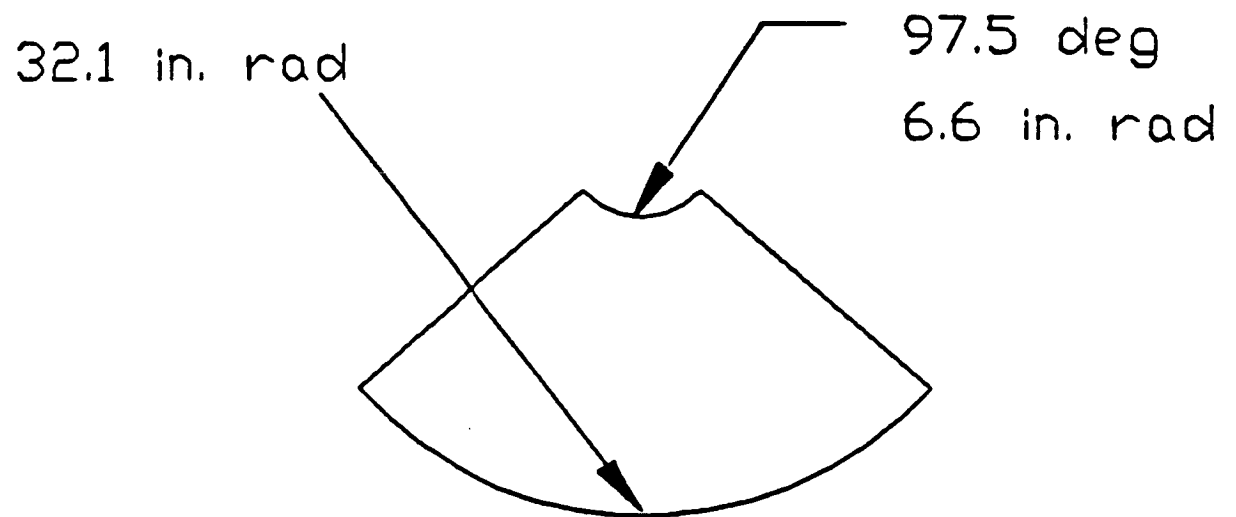


FIGURE 1.10

# CENTER TEMPLATE

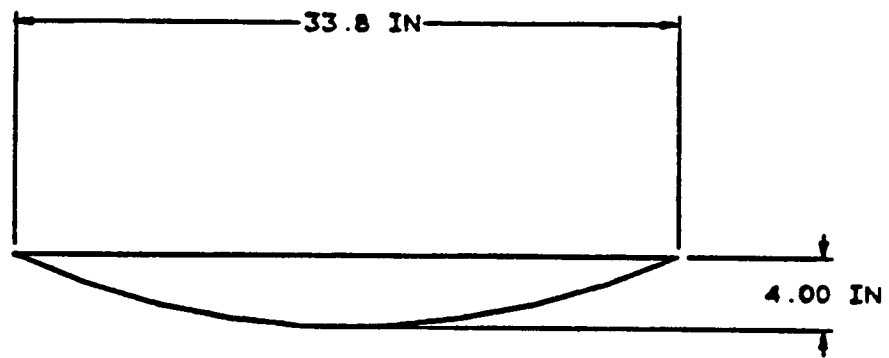


FIGURE 1.11

## UPPER SHELL FRAME

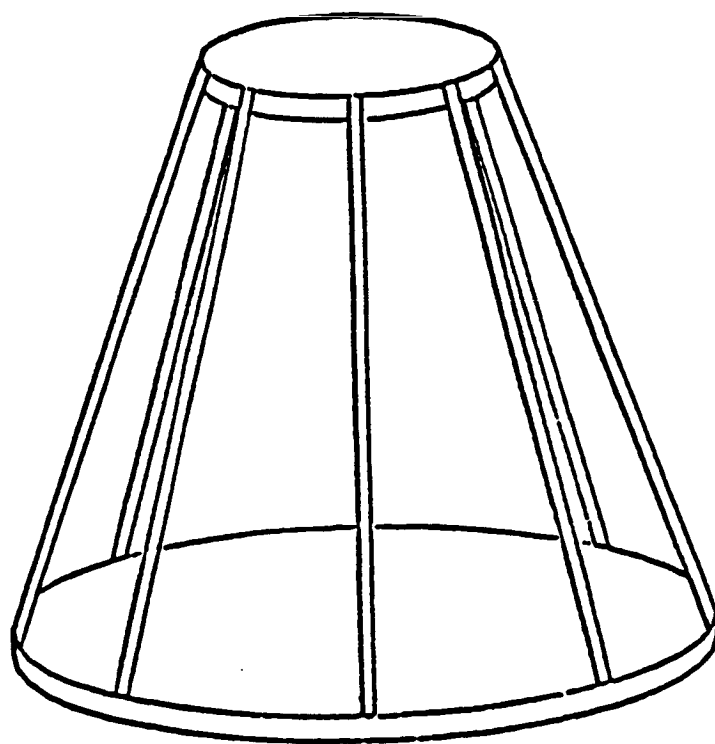


FIGURE 1.12

### Step 5

The lower bowl is complete and should resemble Figure 1.13. The top and bottom covers for the upper shell of the S-glass model can be cut from an S-glass sheet. From this mold the ACRV model can be constructed. The mold will be saved for possible later use or modification.

## 7.2 Shell Construction

The ACRV model shell is a sandwich construction consisting of fiberglass and resin over a core material (see Figure 1.14). The fiberglass and resin are analogous to the flanges of an I-beam with the core material serving as the webbing. For the ACRV model, the composite is S-glass fiberglass and polyester resin matrix, and the core material is polyvinyl chloride.

The glass fibers come in the form of bi-directional cloth, unidirectional cloth, or as a glass fiber mat. The ACRV model requires strength in all directions and must be waterproof. A combination of the bi-directional cloth and mat will effectively fulfill this requirement (Figure 1.15).

Polyester resin is a thermosetting plastic. This means that it is cured, or hardened by heat. Heat is normally generated internally by using a catalyst, but curing can be accelerated by externally heating with heat lamps or a heat gun. A filler material consisting of tiny, hollow glass spheres, called micro balloons, is mixed with resin into a paste and spread onto the foam. This mixture acts as a lightweight filler for any holes in the foam and aids in waterproofing.

There are different materials available for use as core materials, however foamed plastics are a popular type of core material. Polyvinyl chloride plastic (PVC) is the material chosen for use in the ACRV model. PVC foam is a closed-cell material, therefore it cannot absorb water. Also, the polyvinyl chloride can be used with polyester resin.

There are a variety of tools required when working with fiberglass. There should be buckets and cans available for holding resin and for mixing the catalyst. Paint brushes are needed for applying the resin. Squeegees should be kept on hand for removing excess resin from the glass fiber cloth and mat. Also, cutting equipment for shaping the fiber cloth and mat is needed. Finally, rags are essential for cleaning up extra resin. Once the fiberglass has hardened, files, hacksaws, and other cutting tools are used to shape the cured fiberglass.

The first step in the construction involves building a mold. The mold is slightly smaller than the desired dimensions of the model, so that once the fiberglass and foam have been applied, the model will have the correct external dimensions. The next step is to apply fiber cloth to the mold surface and saturate it with resin. Next, the PVC foam is attached to the



## LOWER SHELL PATTERN

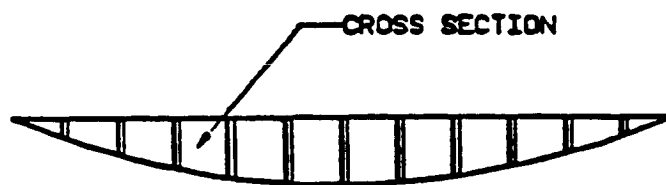


FIGURE 1.13

# SANDWICH CONSTRUCTION

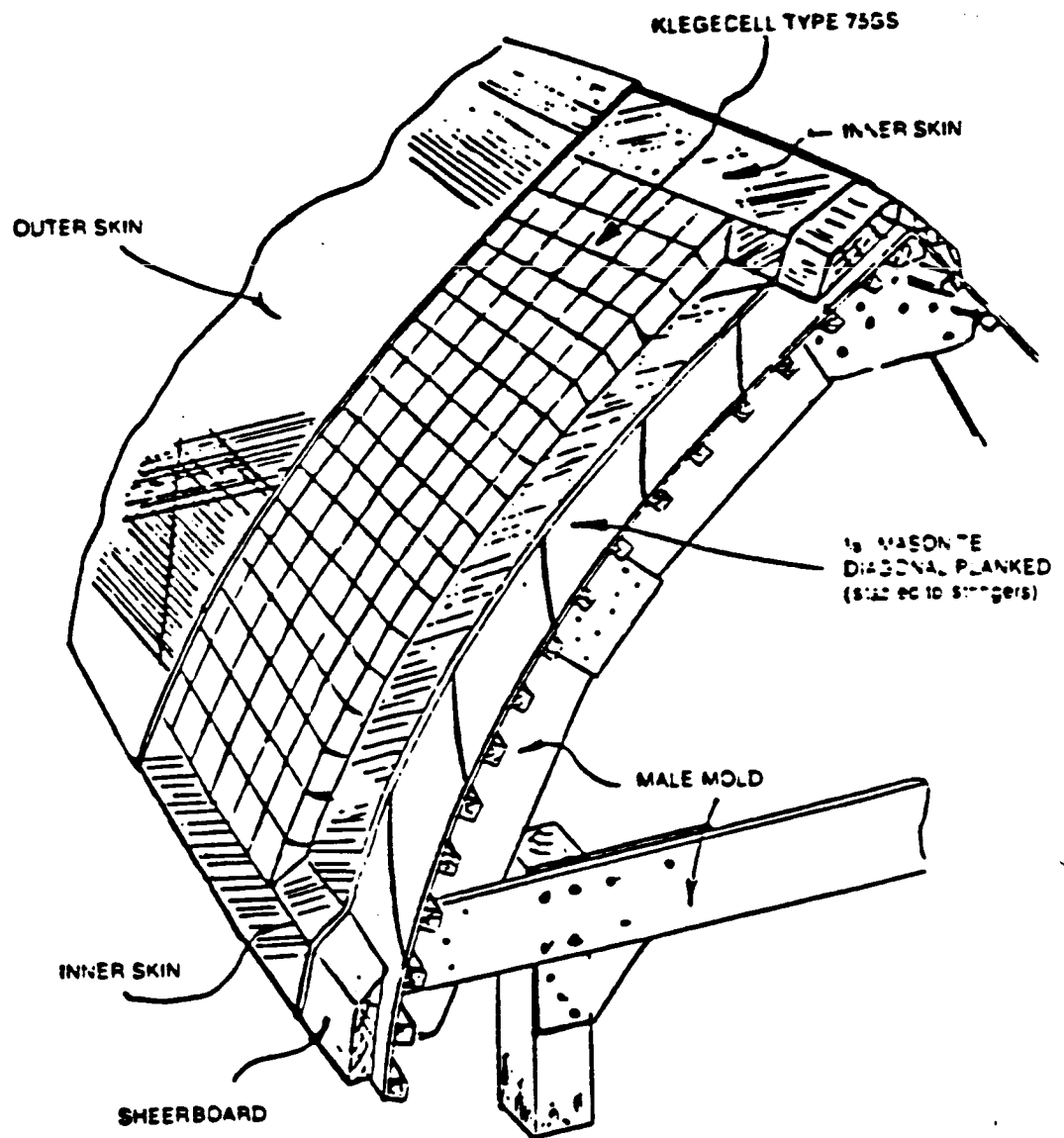


FIGURE 1.14

## BIDIRECTIONAL WOVEN FIBER CLOTH

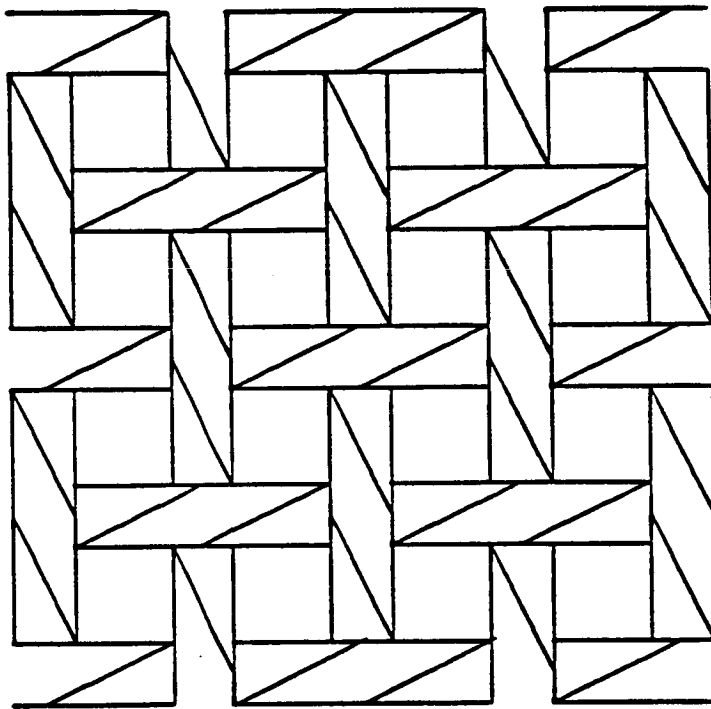


FIGURE 1.15

fiber cloth on the mold. The PVC foam should be pre-cut to the correct shape leaving excess material on the edges for final shaping. The plastic foam comes pre-cut with lateral and longitudinal grooves to enable bending it to fit the complicated shape of the ACRV model. To minimize resin absorption into the PVC foam and improve waterproofing, a thick mixture of resin and micro balloons is spread thinly over the exterior of the foam. A fiber mat is then placed on the PVC foam and saturated with resin. A layer of fiber cloth is placed on top of the fiber mat. The addition of the fiber mat to the outside skin adds strength and waterproofing. Finally, excess resin is removed using squeegees.

Several hard points must be provided in the construction of the ACRV model. Hard points are places where the shell strength has been increased so that other objects may be attached to the model. Wherever hard points are needed, the PVC foam is replaced with layers of glass fiber mat and resin. The addition of fiber mat and resin provides the additional shear strength necessary to attach various objects to the model [7].

Throughout the life of the model, accidents may require the model to be repaired. A crack can be repaired by applying a section of saturated fiber cloth over the entire crack. This cloth will bond completely with the previously cured fiberglass. A disadvantage is that the shape of the model will be altered slightly. However, this slight change in the shape of the model should not affect its performance capabilities. A hole in the model can be repaired by cutting out a clean section around the hole. The next step is to place a new piece of resin saturated fiber cloth on the inside of the model. Next the hole will be filled with spare PVC foam. Finally, the outside skin will be completed by placing fiber cloth and mat on top of the foam. If an attachment rips out of a hardpoint, a more complicated repair is required. The hardpoint is repaired by cutting out the old hardpoint section and enlarging the hole. A new hardpoint is then built into the hole with extra reinforcing layers of glass spread out over the area surrounding the hardpoint.

If water intrusion occurs, it can be corrected by recoating with polyester resin. The bulk of the waterproofing of fiberglass comes from the resin [8].

The use of fiber reinforced plastics for constructing the ACRV model offers many advantages. The material is strong, lightweight, and waterproof. The polyester resin, the fiber reinforcing materials, and PVC foam do not create health hazards. An ACRV model made of fiberglass will be relatively easy to construct and simple to repair.

## Chapter 8.0 CENTER OF GRAVITY AND MASS MOMENT

Refer to Figures 1.18 - 1.19 for a description of the work schedule milestone chart for the CG and Mass Moment construction.

# MODEL CONSTRUCTION SCHEDULE

## A.1 Review Requirements

- A.1.1 Requirements [1/7-1/14]
- A.1.2 Drawings [1/7-1/14]
- A.1.3 Physical Characteristics [1/7-1/14]

## A.2 Drawings

- A.2.1 Sketches [1/14-1/21]
- A.2.2 Detailed Construction Drawings [1/14-1/21]

## A.3 Material Acquisition

- A.3.1 Construction Materials [1/24-1/27]
- A.3.2 Construction Tools [1/24-1/27]

## A.4 Fabrication

- A.4.1 Plug [1/25-2/1]
- A.4.2 Female Fiberglass Casting [2/1-2/14]
- A.4.3 Shell Lay-up (Stabilization) [2/15-2/23]
- A.4.4 Stabilization Integration [2/23-2/25]
- A.4.5 Shell Lay-up Egress [2/24-3/3]
- A.4.6 Egress Integration [3/3-3/5]

## A.5 Pretest

- A.5.1 Floatation [2/23-3/5]
- A.5.2 Leakage [2/23-3/5]
- A.5.3 Stress Loading [2/23-3/5]
- A.5.4 Accessibility [2/23-3/5]

## A.6 Finishing

- A.6.1 Paint [3/8-3/15]
- A.6.2 Decal [3/8-3/15]

FIGURE 1.16

# MODEL CONSTRUCTION MILESTONE CHART

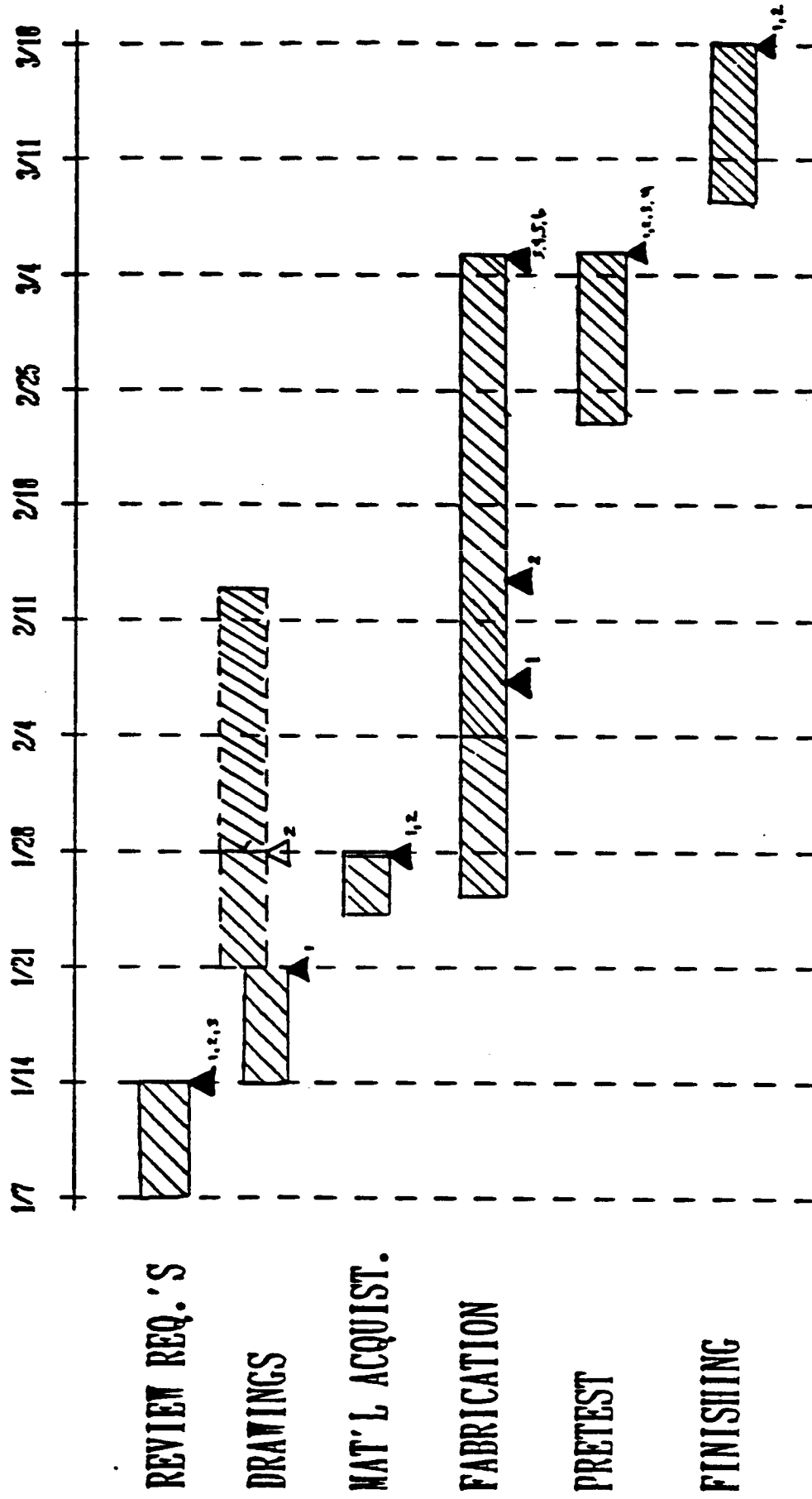


FIGURE 1.17

# CG AND MASS MOMENT OF INERTIA CONSTRUCTION SCHEDULE

## B.1 Review Requirements

- B.1.1 Requirements [1/29-2/3]
- B.1.2 Drawings [1/29-2/5]
- B.1.3 Physical Characteristics [1/29-2/5]

## B.2 Drawings

- B.2.1 Sketches [1/29-2/5]
- B.2.2 Detailed Construction Drawings [1/29-2/5]

## B.3 Material Acquisition

- B.3.1 Construction Materials [2/15-2/23]
- B.3.2 Construction Tools [2/15-2/23]

## B.4 Fabrication

- B.4.1 Plates [2/23-3/2]
- B.4.2 Alternative Plates (w/ or w/out couch) [2/23-3/2]

## B.5 Pretest

- B.5.1 Mass of Vehicle [3/2-3/9]
- B.5.2 Variability of CG & Mass Moment [3/2-3/9]

## B.6 Finishing

- B.6.1 Paint [3/8-3/15]
- B.6.2 Decal [3/8-3/15]

FIGURE 1.18

# CG AND MASS MOMENT OF INERTIA MILESTONE CHART

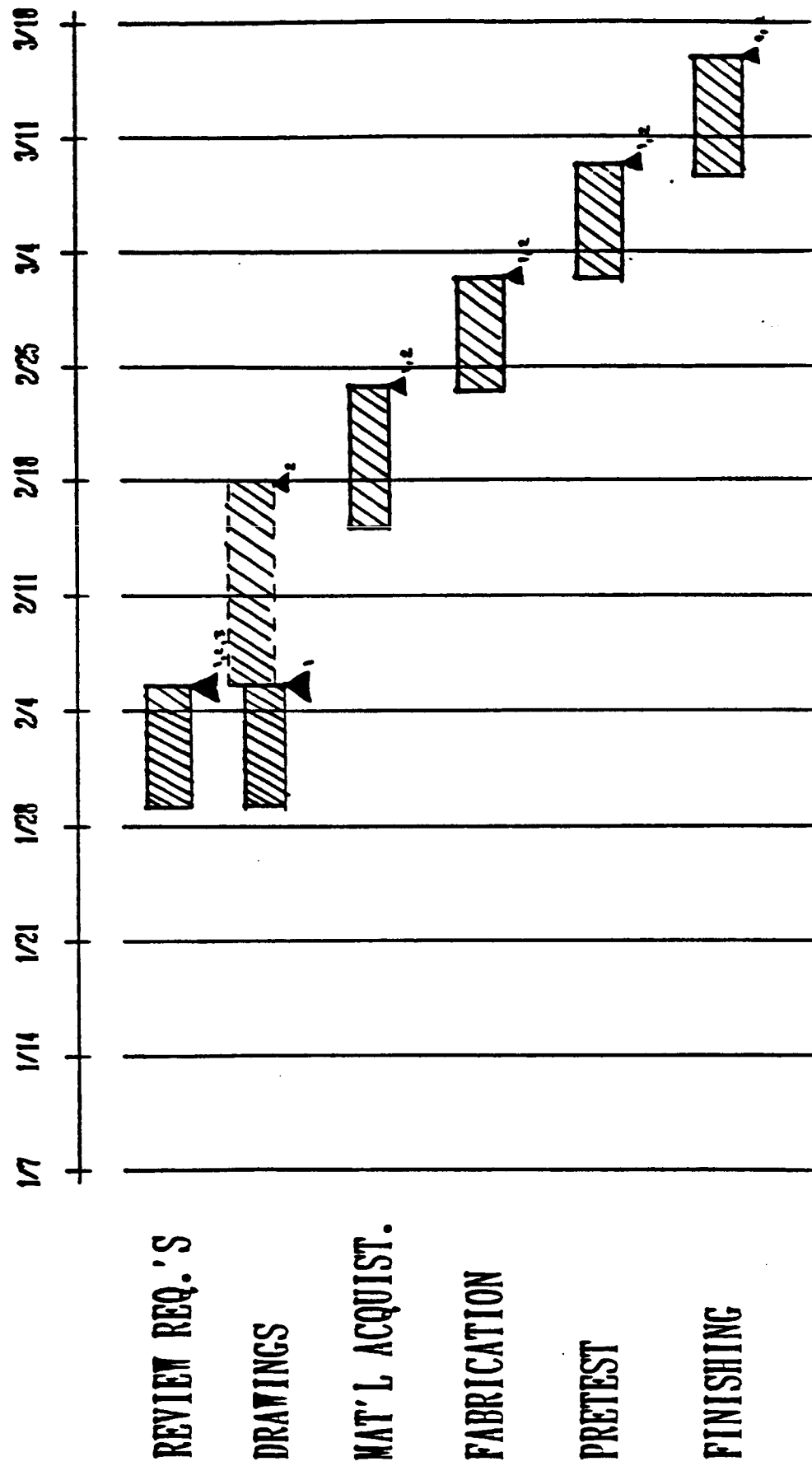


FIGURE 1.19



## **TESTING PHASE - ACRV MODEL CONSTRUCTION**

### **Chapter 9.0 TEST PLAN**

This test plan details test objectives and procedures along with data collection techniques applicable to the acceptance of the ACRV model as an operational testbed. Tests include size, weight, and shape verifications, water tightness, operational life, interior volume and accommodation techniques for subsystems, and center of gravity variations. These tests were performed at the construction site prior to departure to water testing facility.

#### **- Test #1**

**Objective:** Ensure the ACRV model is geometrically shaped to one-fifth scale based on the Apollo Command Module (ACM) derivative.

**Procedure:** 1.A: Measure the height of the hemispherical base.

- 1.A.1 Position hemispherical base, hollow side up, on floor.
- 1.A.2 Center a 1 x 2 x 40 inch wood stick across the bowl, parallel to the floor.
- 1.A.3 Measure from the floor, with a tape measure, the distance to the lower surface of the stick.
- 1.A.4 Record results.

1.B: Measure the diameter (at widest point) of the hemispherical base.

- 1.B.1 Position the hemispherical base flat face down.
- 1.B.2 Rotate the tape measure onto its side on the outer edge of the hemispherical base at its widest point.
- 1.B.3 Wrap the tape measure around the perimeter.
- 1.B.4  $P = \pi D$ ,  $D = P/\pi$
- 1.B.5 Record results.

1.C: Measure height of conical section

- 1.C.1 Position conical section on floor large diameter down.
- 1.C.2 Center 1 x 2 x 40 inch wood stick across the top face, parallel to floor.

- 1.C.3 Repeat procedure 1.A.3
- 1.C.4 Repeat procedure 1.A.4

1.D: Measure diameter of the widest point of the conical section .

- 1.D.1 Place conical section on floor large diameter down.
- 1.D.2 Rotate tape measure onto its side on the outer edge of the conical section at its widest point.
- 1.D.3 Repeat procedure 1.B.3
- 1.D.4 Repeat procedure 1.B.4
- 1.D.5 Repeat procedure 1.B.5

1.E: Measure diameter of the narrowest point of the conical section.

- 1.E.1 Rotate tape measure onto its side on the outer edge of the conical section at its narrowest point.
- 1.E.2 Repeat procedure 1.B.3
- 1.E.3 Repeat procedure 1.B.4
- 1.E.4 Repeat procedure 1.B.5

Data Collected: Height and diameter of base, height and upper/lower diameters of conical section.

## - Test #2

Objective: Ensure ACRV model is weighted to one-fifth scale of 16,000 lb ACM derivative.

Procedure: 2.A: Weigh the ACRV model with subsystems incorporated.

- 2.A.1 Place ACRV model with subsystems on beam/balance scale.
- 2.A.2 Record results.
- 2.A.3 Divide 16,000 lb by the cube of the scale factor ( $5^3$ ). Total scaled weight.
- 2.A.4 Compare 2.A.2 to 2.A.3

2.B: Weigh ACRV model without subsystems incorporated.

- 2.B.1 Repeat procedure 2.A.1

**2.B.2 Repeat procedure 2.A.2**

**Data Collected:** Overall ACRV model weight.

**- Test #3**

**Objective:** Verify seal integrity and water tightness of ACRV model.

**Procedure:** 3.A: Submersion test

- 3.A.1 Place model into adequate size body of water.
- 3.A.2 Apply weight necessary to submerge model in water past break point.
- 3.A.3 Maintain submersion for 50 minutes.
- 3.A.4 Remove model from water.
- 3.A.5 Place ACRV model on a beam/balance scale.
- 3.A.6 Record results.
- 3.A.7 Compare to procedure 2.B.2.

**Data Collected:** Water accumulation through submergence.

**- Test #4**

**Objective:** Ensure hardpoint accommodations have been met for the incorporation of rapid egress system into the model.

**Procedure:** 4.A:

- 4.A.1 Visually inspect and photograph interior of model for hardpoint placement.
- 4.A.2 Attach egress system to the interior of model.
- 4.A.3 Apply an adequate force vertically then horizontally, by hand, to ensure attachment strength.
- 4.A.4 Visually inspect for any obstruction or interference from model itself.
- 4.A.5 Record findings.

**Data Collected:** Hardpoint and interference identification.

**- Test #5**

**Objective:** Ensure hardpoint accommodations have been met for the incorporation of the stabilization system to the model.

**Procedure:** 5.A:

- 5.A.1 Visually inspect and photograph exterior of model for hardpoint placement.
- 5.A.2 Attach stabilization system to the exterior of model.
- 5.A.3 Apply adequate force, by hand, to stabilization components to ensure attachment strength.
- 5.A.4 Visually inspect for any obstruction or interference from model itself.
- 5.A.5 Record findings.

**Data Collected:** Hardpoint and interference identification.

**- Test #6**

**Objective:** Ensure the variability and stability of the center of gravity subsystem. (to simulate the movement of couch to hatch).

**Procedure:** 6.A: CG movement capability

- 6.A.1 Separate hemispherical base from conical section.
- 6.A.2 Place CG system in slot 3.25 inches in the +z-direction.
- 6.A.3 Attach conical section to hemispherical base.
- 6.A.4 Repeat procedure 3.A.1.
- 6.A.5 Position a camera 8 ft from model at a height 2 in. above water line. Position the camera parallel to the calm water line.
- 6.A.6 Take photograph for pitch rotation angle measurement.
- 6.A.7 Remove model from water and separate hemispherical base from conical section.
- 6.A.8 Repeat procedures 6.A.2 - 6.A.7, placing CG system in each supplied slot to simulate egress motion toward hatch.

**Data Collected:** Model's variable CG range and effects.

- Test #7

Objective: Measure mass moment of inertia of the model.

Procedure: 7.A: Swinging the model

- 7.A.1 Repeat procedure 7.A.1.
- 7.A.2 Suspend model from ceiling support at the eye-hook.
- 7.A.3 Pull the model approximately 20 degrees to one side, being careful to keep the centerline of the model collinear with the wire, and release it from rest.
- 7.A.4 Using a stopwatch, measure and record the time required for ten complete oscillations of the pendulum.
- 7.A.5 Repeat procedures 7.A.3 - 7.A.4 five times.
- 7.A.6 Record time (t), calculate period =  $2\pi t/\text{cycles}$ , and record.
- 7.A.7 Repeat procedures 7.A.1 - 7.A.6 with the eye-hook secured in the center of the hemispherical base.

Data Collected: Mass moment of inertia.

Chapter 10.0 TEST DATA

Test #1

- 1.A) Hemispherical Base Height - 5.5 in.
- 1.B) Hemispherical Base Diameter - 35.75 in.
- 1.C) Conical Section Height - 22.25 in.
- 1.D) Conical Section Diameter (Narrowest Pt.) - 7.0 in.
- 1.E) Conical Section Diameter (Widest Pt.) - 35.75 in.

Test #2

- 2.A) ACRV Model Weight (W/Subsystems) - 131 lbs.
- 2.B) ACRV Model Weight (W/O Subsystems) - 47.9 lbs.
- Actual ACRV Weight (Test 2.A \* 125) - 16,375 lbs.

Test #3

- 3.A) ACRV Model Weight (After Submergence) - 131.5 lbs.

Test #4

- 4.A) Interior of model was inspected to verify hardpoint placement. Egress system was attached to model floor and pressure applied. Hardpoints provided adequate strength and no visible obstructions or interference was noted.

Test #5

- 5.A) Exterior of model was inspected to verify hardpoint placement. Stabilization system was attached to model periphery and pressure applied. Hardpoints provided adequate strength and no visible obstructions or interference was noted.

Test #6

- 6.A) Observed pitch angle at 0.0 in - 0 deg.  
Observed pitch angle at 3.25 in - 1 deg.  
Observed pitch angle at 6.50 in - 1.5 deg.  
Observed pitch angle at 9.75 in - 2 deg.  
Observed pitch angle at 13.0 in - 3 deg.

Test #7

- 7.A) Moment of inertia determination.

The mass of the model is: 4.06832 slugs.

Suspend the model from the top:

Repetition	1	2	3	4	5	mean
Time (sec)	19.94	19.82	19.9	19.77	19.88	19.862
Period	1.994	1.982	1.99	1.977	1.988	1.9862

Suspend the model from the bottom:

Repetition	1	2	3	4	5	mean
Time (sec)	15.19	15.13	15.62	15.33	15.56	15.366
Period	1.519	1.513	1.562	1.533	1.556	1.5366

Resulting in the equation:

$$8.13664596 L^2 + 13.2485 L + -25.61$$

$$K = 3.31827$$

$$\text{LENGTH} = 1.93307 \text{ FEET}$$

$$\text{MASS MOMENT} = 3.39614 \text{ SLUG} \cdot \text{FT}^2$$

## Chapter 11.0 TEST RESULTS AND OBSERVATIONS

This portion of the test report addresses the objective of each test performed along with the procedures used and data collected. Observations and recommendations are also given for each test.

### - Test #1

- 1.A: Test 1.A was performed to measure the height of the model's hemispherical base for comparison to the design specification of the ACRV model. Procedures 1.A.1 - 1.A.4 of the test plan were followed.

The height of the hemispherical base measured in Test 1.A was 5.5 inches. Design specifications for the base height required 5.0 inches. The discrepancy encountered resulted from the thickness of the fiberglass and human error during plug construction. This may be corrected by closer tolerances on the fiberglass thickness and more attention paid to plug construction.

- 1.B: Test 1.B was performed to measure the diameter of the model's hemispherical base at the widest point for comparison to the design specification of the ACRV model. Procedures 1.B.1 - 1.B.5 of the test plan were followed.

The diameter of the hemispherical base at the widest point measured in Test 1.B was 35.75 inches. Design specifications for the base diameter required 34.8 inches. The discrepancy encountered resulted from the thickness of the fiberglass and human error during plug construction. This may be corrected by closer tolerances on the fiberglass thickness and more attention paid to plug construction.

- 1.C: Test 1.C was performed to measure the height of the model's conical top for comparison to the design specification of the ACRV model. Procedures 1.C.1 - 1.C.4 of the test plan were followed.

The height of the conical top measured in test 1.C was 22.25 inches. Design specifications for the top height required 21.4 inches. The discrepancy encountered resulted from the thickness of the fiberglass and human error during plug construction. This may be corrected by closer tolerances on the fiberglass thickness and more attention paid to plug construction.

- 1.D: Test 1.D was performed to measure the diameter of the model's conical top at the widest point for comparison to the design specification of the ACRV model. Procedures 1.D.1 - 1.D.5 of the test plan were followed.

The diameter of the conical top at the widest point measured in Test 1.D was 35.75 inches. Design specifications for the top diameter required 34.8 inches. The discrepancy encountered resulted from the thickness of the fiberglass and human error during plug construction. This may be corrected by closer tolerances on the fiberglass thickness and more attention paid to plug construction.

- 1.E: Test 1.E was performed to measure the diameter of the model's conical top at the narrowest point for comparison to the design specification of the ACRV model. Procedures 1.E.1 - 1.E.5 of the test plan were followed.

The diameter of the conical top at the narrowest point measured in Test 1.E was 7.0 inches. Design specifications for the top diameter required 7.2 inches. The discrepancy encountered resulted from the thickness of the fiberglass and human error during plug construction. This may be corrected by closer tolerances on the fiberglass thickness and more attention paid to plug construction.

## **- Test #2**

- 2.A: Test 2.A was performed to weigh the ACRV model with subsystems incorporated for comparison to design specifications for the ACRV model with subsystems incorporated. Procedures 2.A.1 - 2.A.4 of the test plan were followed.

The weight of the model measured in Test 2.A was 131 pounds. Design specifications for the model required 128 pounds. The discrepancy encountered resulted from three pounds of additional hardware. This could have been corrected by anticipating problems related to assembly.

- 2.B: Test 2.B was performed to weigh the ACRV model without subsystems incorporated for comparison to design specifications for the ACRV model



without subsystems incorporated. Procedures 2.B.1 - 2.B.2 of the test plan were followed.

The weight of the model measured in Test 2.B was 47.9 pounds. Design specifications for the model weight without subsystems were left open so that the true weight after construction could be determined.

**- Test #3**

**3.A:** Test 3.A was performed to verify the seal integrity and water tightness of the model. Procedures 3.A.1- 3.A.7 of the test plan were followed.

The model was submerged for a period of fifty (50) minutes. The amount of water taken on increased the weight of the model by 1/2 lb. Design specifications required no leakage of water into the model. The discrepancy encountered was deemed acceptable and no further action was taken. Further research into seals may have reduced the amount of water leakage.

**- Test #4**

**4.A:** Test 4.A was performed to ensure hardpoint accommodations for the incorporation of the rapid egress system. Procedures 4.A.1 - 4.A.5 of the test plan were followed.

The model had the hard points necessary for attachment. Forces applied to the model did not separate the rapid egress system from the model. No obstruction of the rapid egress system's operation was caused by the model.

**- Test #5**

**5.A:** Test 5.A was performed to ensure hardpoint accommodations for the incorporation of the stabilization system. Procedures 5.A.1 - 5.A.5 of the test plan were followed.

The model had the hard points necessary for attachment. Forces applied to the model did not separate the stabilization system from the model. No obstruction of the stabilization system's operation was caused by the model.

**- Test #6**

**6.A:** Test 6.A was performed to ensure the variability and stability of the center of gravity subsystem. Procedures 6.A.1 - 6.A.8 of the test plan were followed.

The observed pitch angle at 0 in. was 0.0°. The angle at 3.25 in. was 1.0°. The angle at 6.5 in. was 1.5°. The angle at 9.75 in. was 2.0°. The angle at 13 in. was 3.0°.

**- Test #7**

**7.A:** Test 7.A was performed to determine the mass moment of inertia of the model. Procedures 7.A.1 - 7.A.7 of the test plan were followed.

The mass moment of inertia of the model measured in Test 7.A was determined to be 3.39 slug ft<sup>2</sup>. Design specifications for the model moment of inertia required 3.2 slug ft<sup>2</sup>. The discrepancy encountered resulted from the extra weight of the model. This could have been corrected if the model weighed the desired weight or by repositioning the weights.

## **SECTION II.**

### **WATER TEST FACILITY**

#### **DESIGN PHASE**

- **EXISTING WATER TEST FACILITIES IDENTIFIED**
- **CONSTRUCTION OF PERMANENT FACILITY AT UCF**



## **SECTION II. WATER TEST FACILITY**

### **INTRODUCTION**

The objective of this design effort is to identify a water test facility where stabilization tests on the ACRV model can be performed. This includes researching existing facilities as well as establishing designs for a permanent facility at the University of Central Florida (UCF). The test location selected will be an existing facility, therefore, building and testing phases are not included in this section.

### **DESIGN PHASE - WATER TEST FACILITY**

A testing facility provides a controllable simulation of ocean conditions. An environment capable of producing waves on a continuous scale from 0 to 1.5 ft. is desired. Wind is also desired, however, its scaled down effects may be disregarded. The facility must be large enough to accommodate the model and provide for ready access. In addition, other factors such as cost and location are considered.

The purpose of this section is to determine the means to satisfy the specified objectives. The goals may be met through either the design and construction of a facility or through the identification of an existing facility. The options available in each case are presented.

Chapter 12.0 examines existing water test facilities (WTF's) and details strong and weak points of several facilities. Chapter 13.0 examines designs generated for the construction of a permanent WTF. Finally, Chapter 14.0 summarizes the technical procedure section.

### **Chapter 12.0 EXISTING WATER TEST FACILITIES**

In researching existing facilities the size and capabilities of wave pools, as well as cost, location, measurement equipment, staff, availability, and other features of each facility were considered. To facilitate acquisition of information, a questionnaire was prepared and facilities were contacted and surveyed. This section outlines the best of the facilities including specific advantages and disadvantages of each.

A questionnaire for use in the survey of existing WTF's is shown in Figure 2.1. This form provided uniformity of information. One important question asked was "Do you know of any other facilities that might meet our needs?" As a result approximately fifteen facilities were contacted. Five facilities presented more promise than others and are described below.

# QUESTIONNAIRE

NAME OF FACILITY \_\_\_\_\_

LOCATION OF FACILITY: \_\_\_\_\_

PHONE NUMBER: \_\_\_\_\_

## QUESTIONS TO ASK

Do they have a water test facility? YES\_\_\_/NO\_\_\_

- \* Name of person we should talk with about information on WTF. Do they know of other facilities?
- \* What types of tests are done in your facility? Name of facility:  
Phone number:
- \* What are the dimensions of your test tank? Location:
- \* Can it facilitate a 3'x 3' 100lbs model? YES\_\_\_/NO\_\_\_ Person to contact:
- \* What kind of measurement equipment do you use? (ie, frequency, and endurance of waveforms; to include smoothness and whitecapping?)
- \* Is there an easy access to the model? (ie, hoist, scaffolding, catwalks, etc.) YES\_\_\_/NO\_\_\_ If yes what kind?
- \* Is there a problem with reflection/interference from sides or ends?

FIGURE 2.1

## **12.1 Davidson Laboratory**

Davidson Labs, located at Steven's Institute in Hoboken, New Jersey, provides possibilities for meeting requirements. This facility performed wave testing on the original Apollo capsule. "The Davidson Laboratory has experience in a range of areas, including examination of the stability, control and behavior of all types of marine craft in environments ranging from calm water to random sea states [9]."

Davidson Laboratory has an experienced, full-time staff capable of offering assistance. They have a complete model shop with the capability to build the model on-site. Advanced data acquisition and data processing systems are available. High speed photography and development, underwater visualization as well as high quality measurement equipment and computer modeling are also provided by Davidson. The advantages of this facility lie in its experience, equipment, and personal assistance.

Cost is a disadvantage in considering Davidson Laboratory. The dominant expense involved in the use of this facility is the \$15,000 to \$25,000 testing fee. Other expenses include transportation and lodging. The location itself presents drawbacks. It is likely that fewer team members will be able to attend the testing. Because of cost and location, an extensive test plan will have to be created to assure performance of all tests. Re-testing will be difficult. In addition, depths of the tanks themselves may not be suitable for testing of the model in some configurations. Davidson furthermore provides no wind capabilities, although accommodation for external wind systems is possible.

## **12.2 Coastal Engineering Research Center**

The Coastal Engineering Research Center (CERC), located in Vicksburg, Mississippi, is another WTF being considered. This facility performs mainly harbor simulation and beach erosion; however, accommodation for the ACRV model is possible.

Advantages offered by CERC include: Computer controlled wave generation for the creation of sea states required. Random and directional waves can be formed. A computer is available for data acquisition and processing. CERC also provides for underwater visualization with observation windows below the water line. The wave tank has been designed to minimize reflection and interference from side walls. The facility provides portable catwalks and lifting capability for easy access to the model.

Disadvantages of CERC include: Its inexperience with the specific type of testing required. The deepest tank is 6 feet deep, while 10-12 feet may be required for testing in some configurations. No wind capability is provided. Costs also present a disadvantage. Testing fees may run as high as \$5,000 per week. Transportation and lodging add to expenses as well.

### 12.3 O.H. Hinsdale Wave Research Laboratory

Another facility considered is the O.H. Hinsdale Wave Research Laboratory at Oregon State University in Corvallis, Oregon. This facility provides the capabilities needed. "This is the largest university owned and operated wave channel in the world [10]."

The main wave tank at O.H. Hinsdale is 342 x 12 x 15 feet deep. In contrast to the facilities noted above, depth is not a problem. Other advantages of this facility include: Wave generation machinery consisting of advanced MTS hardware, capable of creating a variety of wave forms. Regular and irregular waves in 2-D can be generated with amplitudes up to 5 feet. Periods ranging from 1.0 second to 10.0 seconds are possible. An elevated control room is located above the main wave tank to provide centralized control and data acquisition [10]. Wave damping is provided by a simulated shore front and minimum interference is encountered from the side walls. The main wave tank is located in environmentally controlled surroundings. Two underwater video cameras may be located in the test section.

Disadvantages exist in the choice of O.H. Hinsdale as a model testing facility. There is no existing wind capability although it is possible to incorporate it. Price is the foremost consideration. "The laboratory operates on a cost reimbursement basis with no support from the State of Oregon [10]." Cost per day at O.H. Hinsdale is \$3,000 (\$1,200 amortization/equipment, \$1,500 personnel, \$300 utilities). In addition, Hinsdale represents the greatest travel distance of all of the facilities that have been considered.

### 12.4 Offshore Technology Research Center

The Offshore Technology Research Center (OTRC) at Texas A&M University in College Station, Texas, is a new, state of the art WTF that opened on October 27, 1990. OTRC provides suitable wave generation capability with a tank large enough to accommodate the ACRV model in all configurations. "The OTRC multi-directional wave model testing facility is designed to study deep water engineering problems in realistically scaled wave environments [11]."

The advantages of OTRC are many. The wave tank is large enough to accommodate any type of testing that is required (100 x 150 x 15/55 feet deep). The wave machine is a 48 segment, hydraulically actuated, hinged flap multi-directional wave generating system capable of producing a wide range of wave spectra. A digital servo-control system, running GEDAP™ software, ensures maximum accuracy, repeatability and optimum performance [11]. To provide damping, a wave absorber is located along the 100 foot long wall of the model basin opposite the wave maker. "As the waves travel from the basin test area into the wave absorber, they encounter panels with progressively decreasing porosity and spacing" [11] (Figure 2.2). An area is provided at the end of the model basin for model construction, assembly, ballasting, and mounting of instruments. The laboratory is also equipped with



## ORTC DAMPING SYSTEM

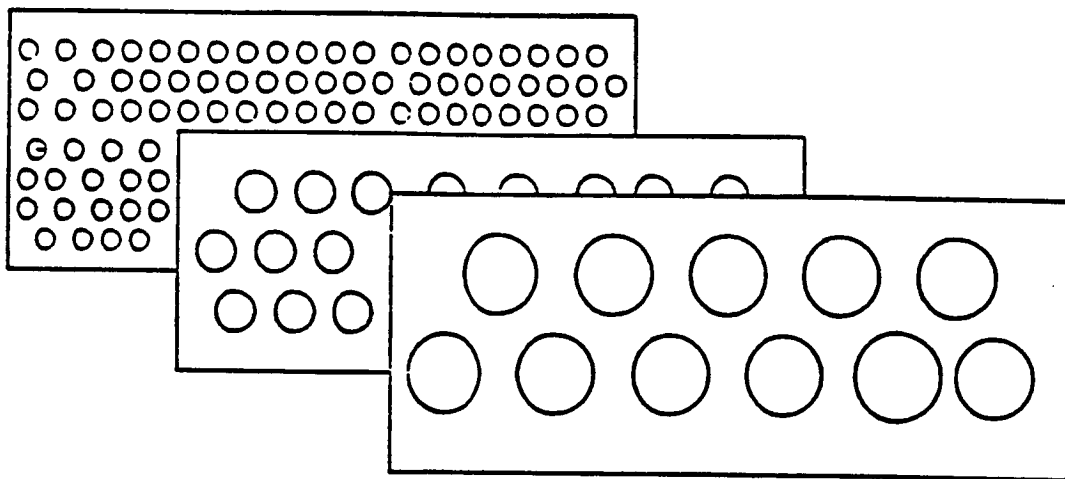


FIGURE 2.2

a full electronics shop for fabrication of special instruments and maintenance of data acquisition and other electronic equipment.

Disadvantages presented by this facility include: OTRC is a new WTF. Peter Johnson, the Facility Manager, states "I am not able to point to a large body of experience or a large suite of instrumentation directly associated with this facility [12]." In addition, the facility provides no wind capability and limited underwater visualization. At this time, it is unclear whether OTRC can provide easy model accessibility. Finally, expenses for transportation must also be considered.

## **12.5 University of Florida**

The University of Florida in Gainesville provides limited wave facilities, but offers an excellent location. Several wave tanks are located at this facility. Two tanks were investigated; a large but shallow (2.0 feet) coastal wave basin with a multi-paddle wave maker, and a deeper (6.0 feet) but narrow (6.0 feet) plexiglass tank with both wave and wind capabilities.

## **12.6 Summary of Existing Facilities**

In general, the use of an existing facility involves advantages and disadvantages which are independent of the specific site chosen. A disadvantage is that availability for re-testing at a later date is not assured and cost may be high. If an existing facility is used, a detailed test plan must be written so that all tests are performed. Another disadvantage in the use of an off-campus site is the necessity of transporting the model, equipment, and personnel. Transporting the model presents logistical, as well as cost problems. On the positive side, an existing facility provides the experience and equipment necessary to make ACRV model testing proceed in an efficient manner. Additionally, observation of a WTF in operation may provide examples and insight that may help in the creation of a permanent WTF at UCF.

## **Chapter 13.0 CONSTRUCTING A PERMANENT FACILITY**

Two approaches are being considered in the design and construction of a permanent facility at UCF. An existing water source may be fitted with the necessary equipment or a permanent facility may be built. The advantages and disadvantages of each approach are outlined in the following pages along with specific designs and floor plans for each case. In chapter 13.1, portable options are explored. Chapter 13.2 details the options and design possibilities for the construction of a permanent facility.

## **13.1 Portable Water Test Facility**

The construction of a portable WTF has advantages and disadvantages: Construction of a portable design should prove to be less expensive than construction of a permanent facility. Portable designs should be able to be made operational in a shorter period of time than a permanent facility. The portable designs considered below offer versatility with regard to water source, quick set-up and storage, and simple construction. However, these designs involve more time constraints, less accuracy, less versatility, and will not provide benefit to other research projects.

### **13.1.1 Water Source**

The water source used in these designs must possess certain properties. It must be large, clear, and available to the testing teams when required. Two possible water sources, a swimming pool and a lake, are being considered.

#### **13.1.1.1 Lake**

The lake provides size, natural damping, and ready availability. However, water clarity is in question, accessibility to the test model is limited, and testing would be subject to environmental influence.

#### **13.1.1.2 Swimming Pool**

The majority of the effort is devoted to designs incorporating the use of a swimming pool. The pool provides many advantages. Water clarity is high. Size and depth requirements can be met. Cost is minimal. Model accessibility should present fewer problems as opposed to the use of a lake. Location can be a major advantage in the choice of a swimming pool. Use of the UCF pool is being considered to provide an on-campus location for testing.

The UCF pool is a Junior Olympic size pool providing good location along with adequate size and depth. The dimensions of the UCF pool are shown in Figure 2.3. There is adequate area surrounding the pool for model maintenance and test equipment. The entire pool area, including a large grass field is enclosed by a chain link fence, providing security for the storage of equipment.

# UCF POOL

UCF JUNIOR OLYMPIC SIZE POOL

POOL DEPTH  
DIVING AREA  
11ft to 6ft  
LAP AREA  
ALL 4ft

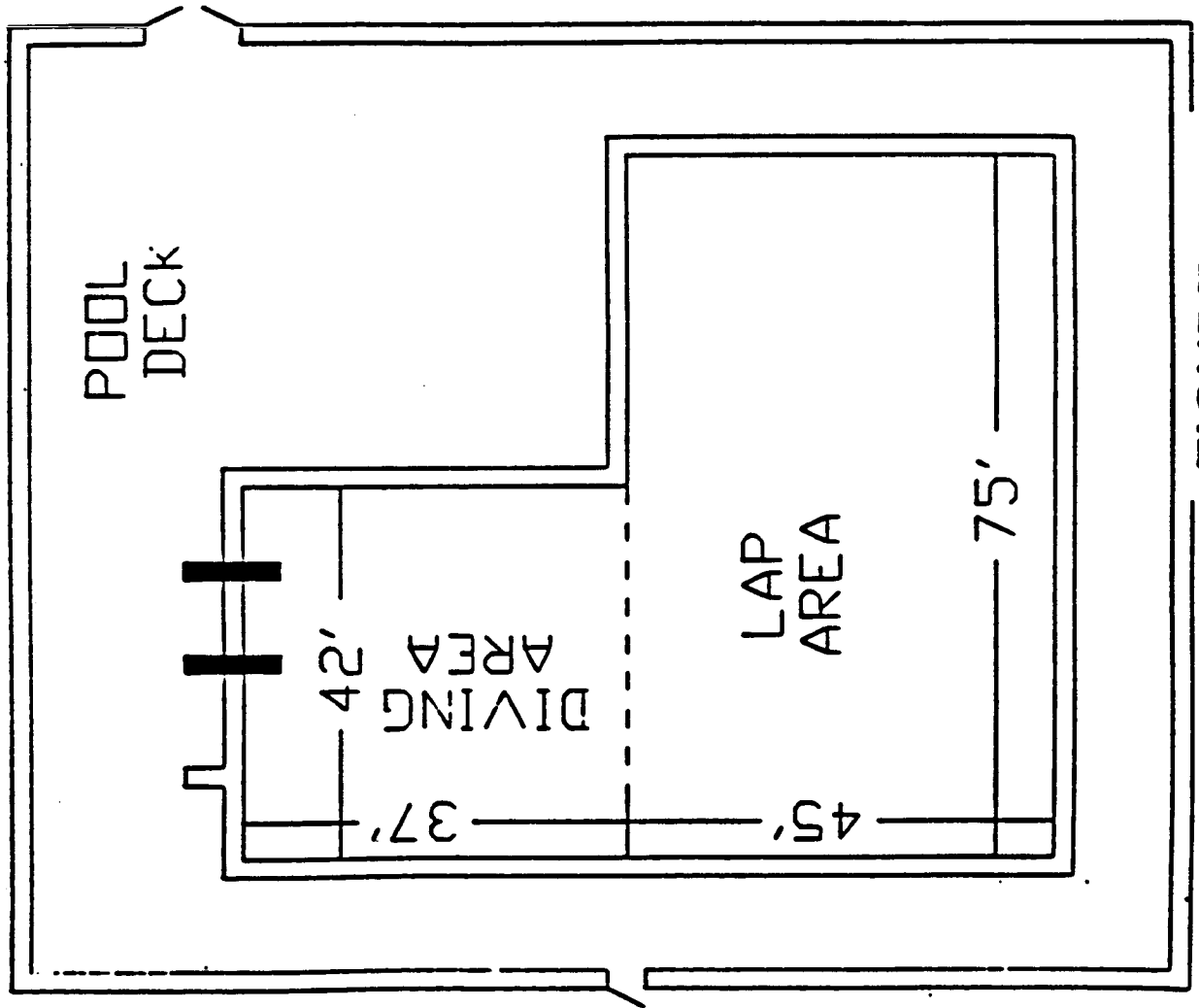


FIGURE 2.3

GRASS AREA

### **13.1.2 Wave Machine**

Several possibilities exist in the choice of a wave generating device for the portable WTF designs. Two types, a piston system and a gate type system, are being considered.

#### **13.1.2.1 Piston Wave Machines**

Ideas for the piston-type wave generator were developed after visiting the wave tank at Walt Disney World's Typhoon Lagoon. As illustrated in Figure 2.4, the piston employs a nozzle to create an up-swelling of water that begins the wave action. As envisioned, the piston apparatus extends over the entire width of the test section. This system provides smooth, clean waves, but actual implementation may be difficult.

#### **13.1.2.2 Gate-type Wave Machine**

An option for wave generation involves the use of a moving gate to push horizontally on a volume of water. Two designs are being considered: A hinged system and a horizontal sliding system.

The hinged gate system (Figure 2.5) features a gate pinned at the bottom. The gate extends over the complete width of the test section and is housed in a strong frame structure. The frame clamps to the lip of the pool at the top and rests on the pool floor. The gate driving mechanism is attached to the rear of the frame and provides a back and forth motion. This system is simple to build and operate. Disadvantages are the limited motion of the gate because it is attached at the bottom.

The slider mechanism (Figure 2.6) uses the same frame as the hinged system. The gate system reciprocates horizontally, causing a uniform wave to be formed. Horizontal motion is constrained by Johnson Rails, a rod and bearing system. The driving mechanism is also the same as in the aforementioned system.

Two types of gates are being considered. A solid gate (Figure 2.7) and one with louvers (Figure 2.8). Each gate is 12.0 feet wide and 2.5 feet tall, half below and half above the calm water line. The solid gate consists of a plywood face with a metal frame allowing no water to flow through. A disadvantage to this configuration is that on the backstroke, a trough may be formed and splashing behind the gate will occur. The louvered gate has a series of louvers extended from the bottom to one half of the gate height. They close on the power stroke and open on the return, limiting trough and splashing. This gate also maintains the plywood and steel frame structure.

# PISTON SYSTEM

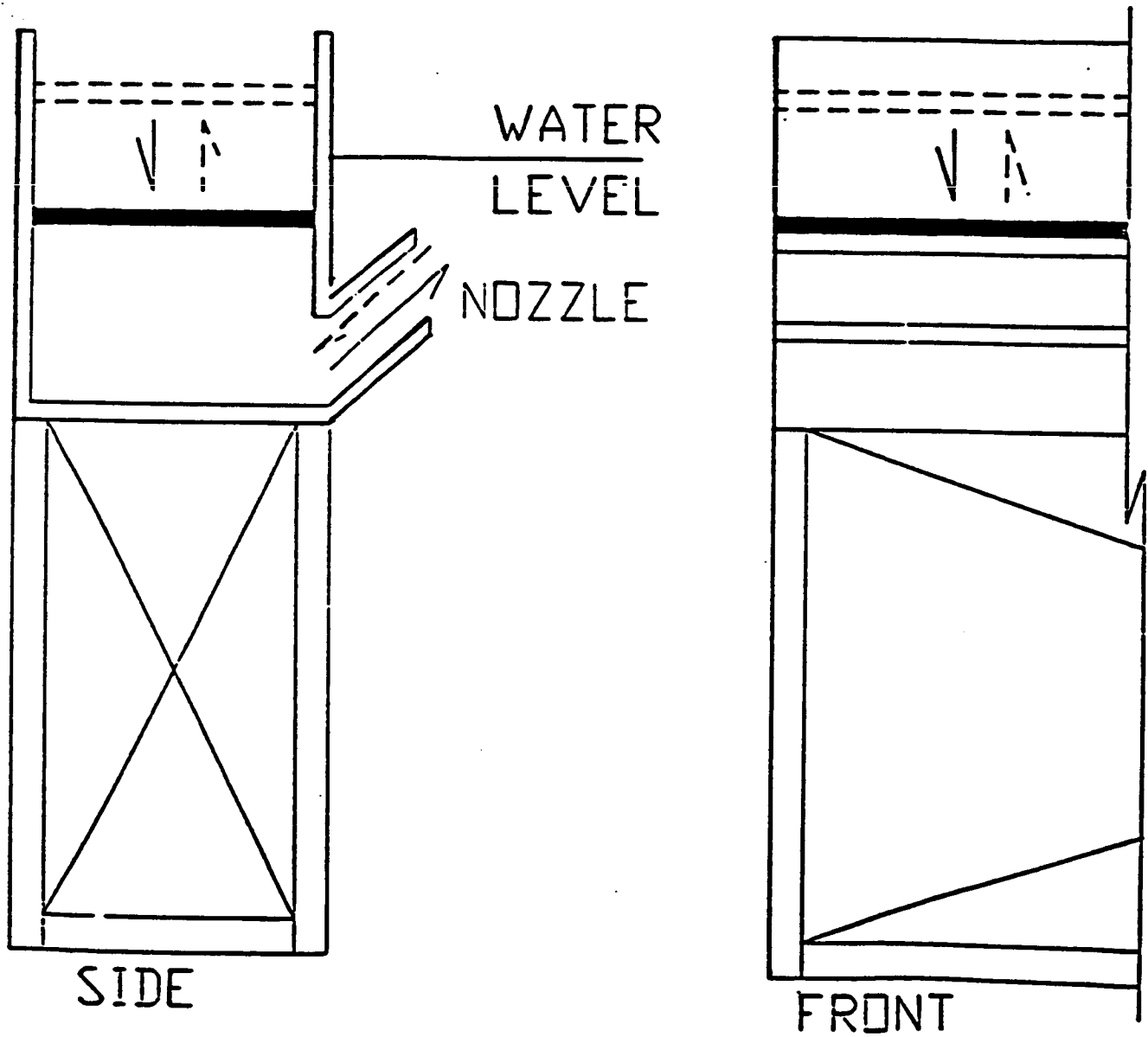


FIGURE 2.4

## HINGED GATE SYSTEM

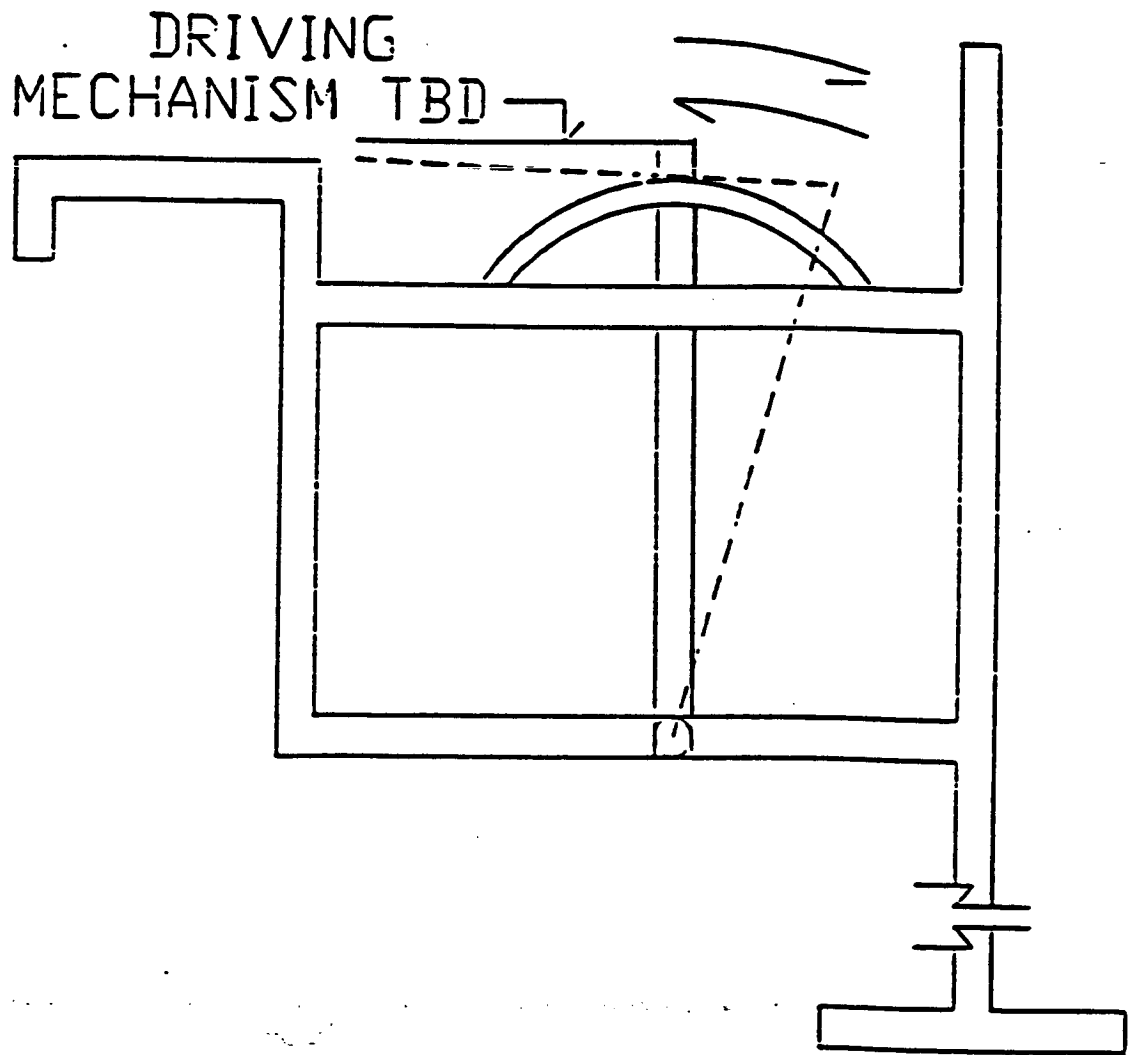
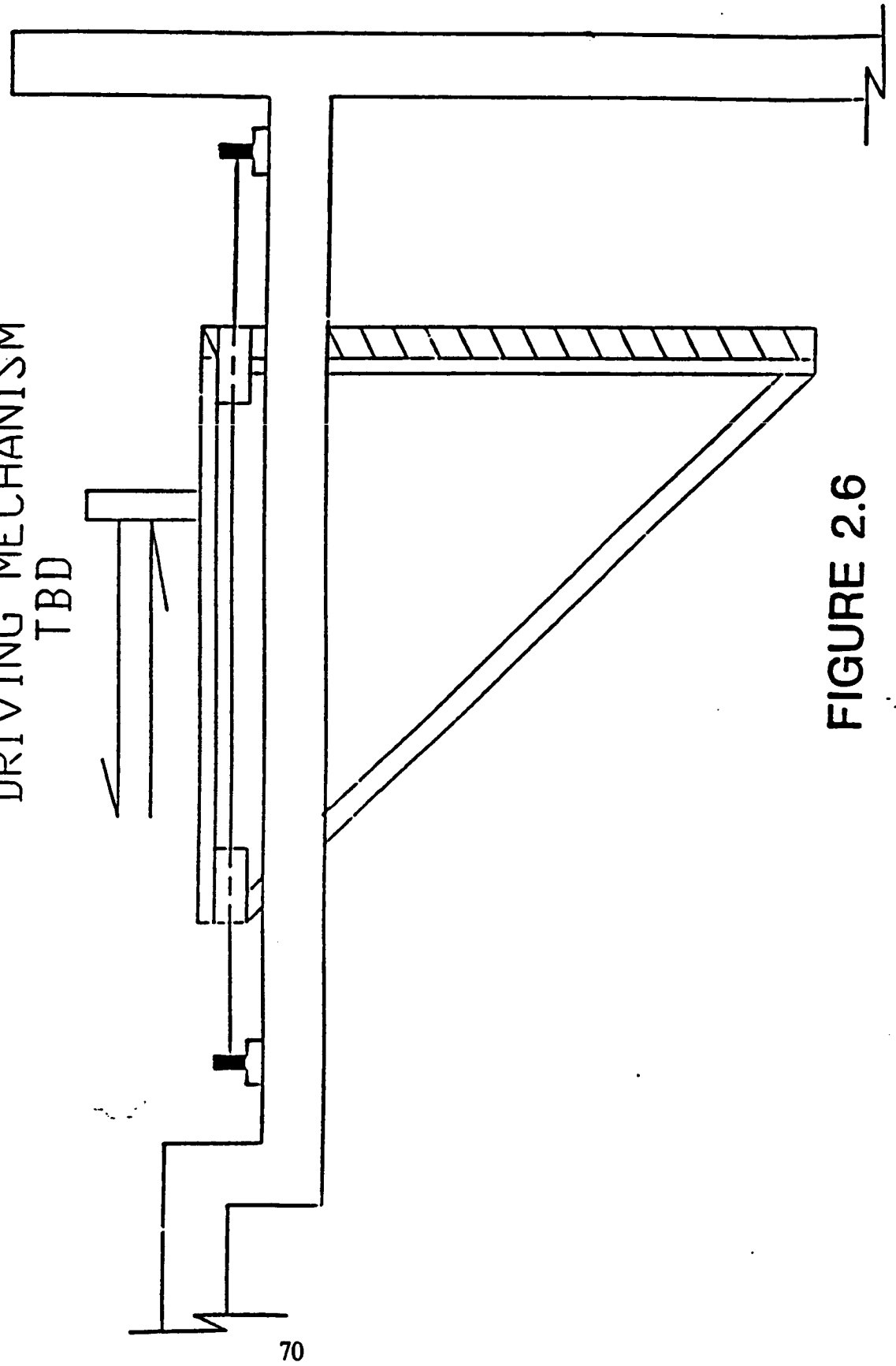


FIGURE 2.5

## SLIDER MECHANISM

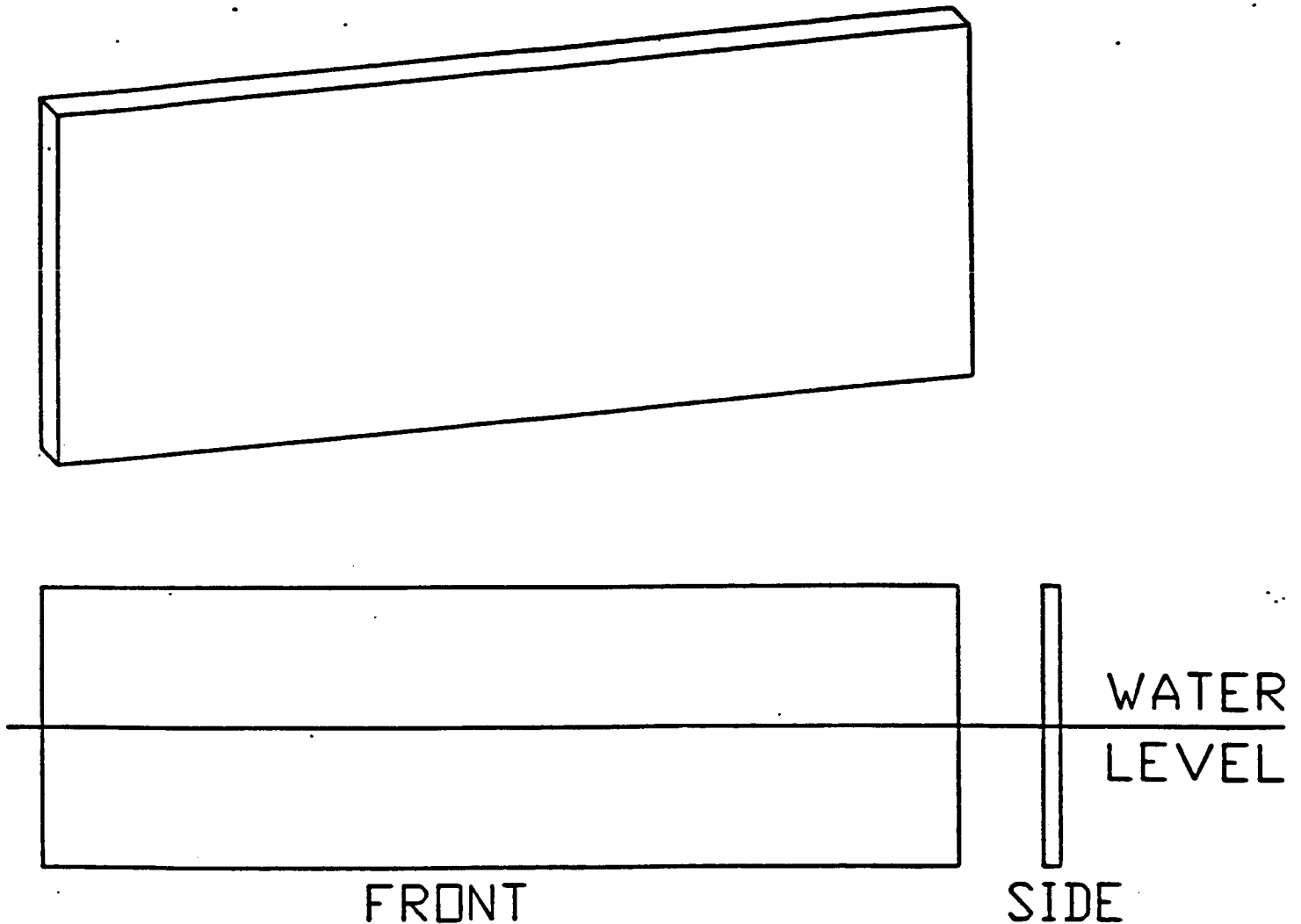
# DRIVING MECHANISM TBD



## FIGURE 2.6



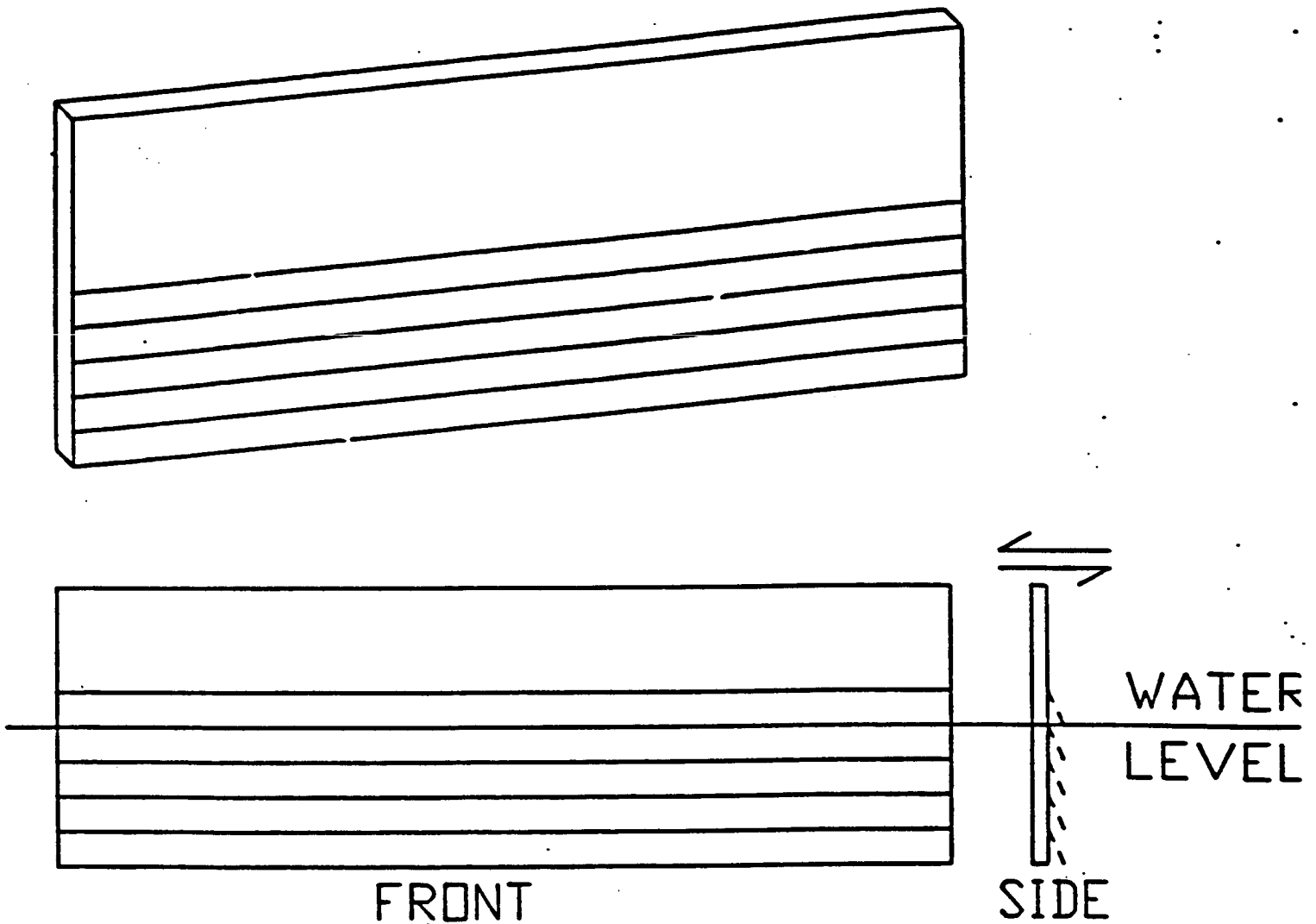
## SOLID GATE SYSTEM



SOLID GATE SYSTEM WILL CAUSE  
A TROUGH IN FRONT AND PUSH  
WATER BACK ON RETURN

FIGURE 2.7

## LOUVERED GATE SYSTEM



LOUVER SYSTEM ON LOWER HALF OF GATE SO A TROUGH IS NOT PRODUCED ON RETURN MOTION.

FIGURE 2.8

### **13.1.3 Wind Machine**

Accurate simulation of sea states may require generation of wind. If wind generation is determined to be important, plans are to acquire a variable speed fan capable of delivering constant wind conditions over the test section.

### **13.1.4 Water Containment**

Generation of waves may cause substantial water splash-out, especially if a swimming pool is used. A bracket system has been devised to allow the edge of the pool to be raised to a level 15.0 inches above the calm water line. This system employs the use of plywood attached to brackets that extend the length of the pool (Figure 2.9). As shown in Figure 2.10, this feature would be important if the UCF pool were used because the water level is only 7 inches below the top of the pool.

### **13.1.5 Damping**

If a swimming pool is used, damping systems may be required to assure minimal interference during testing and to calm the water between tests. In the case of the UCF pool, damping systems are incorporated which take advantage of the physical size of the pool. In the corner of the pool, opposite the wave machine, a barrier is placed at a 45 degree angle directing wave action into a large unused area of the pool (Figure 2.11). If necessary, a damping system is placed in the unused area of the pool. This system consists of an array of plywood gates spanning the width of the pool. Each gate is covered with holes, the holes getting successively smaller with each gate. The floating lane dividers already present may also provide some level of damping.

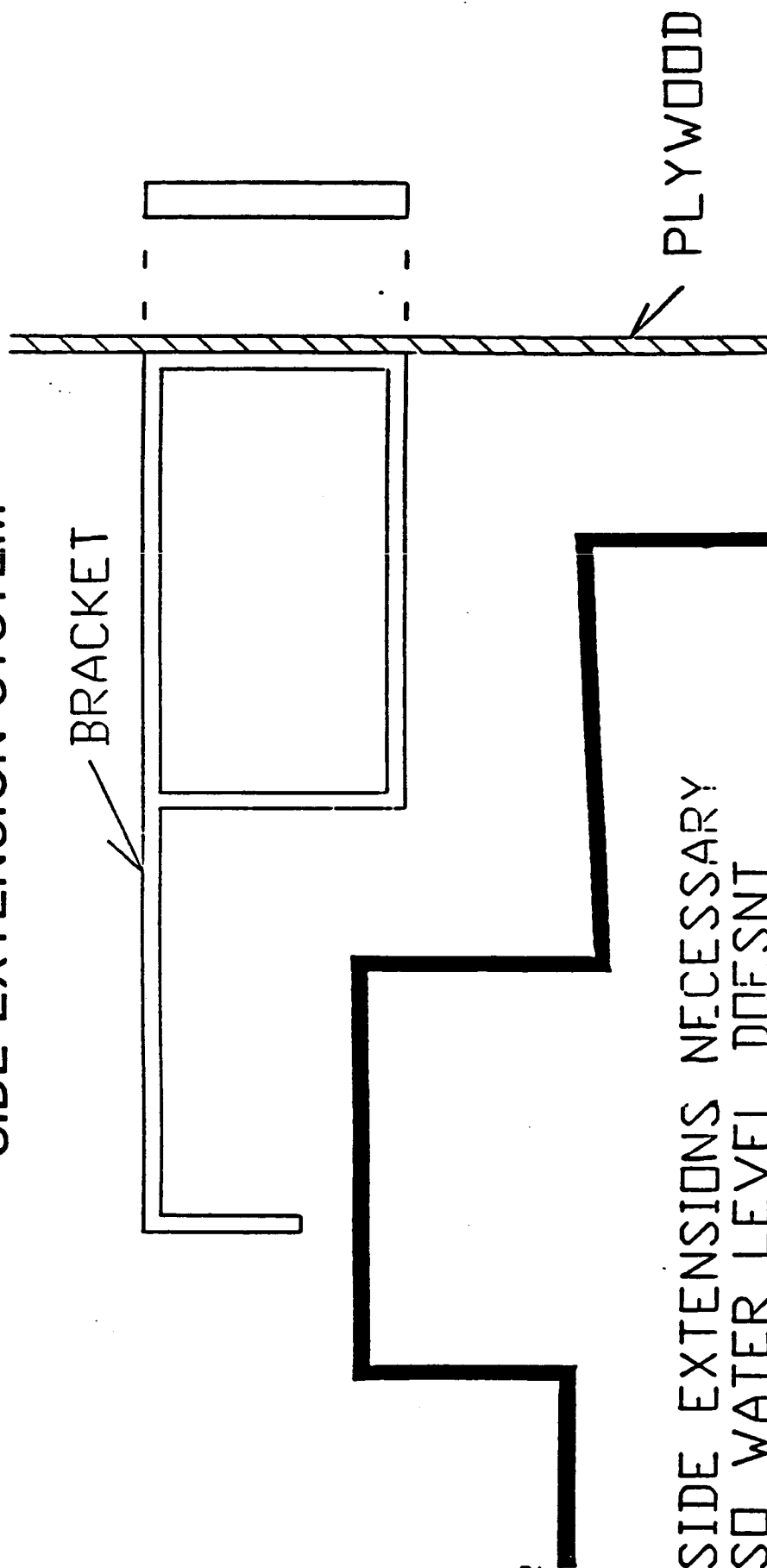
### **13.1.6 Measuring / Recording**

To provide controllable wave forms, it is necessary to measure frequencies and amplitudes of the waves. An accelerometer on a floating device or a float mounted on a measuring stick (Figure 2.12 and 2.13) may be used for the measurement of wave heights and periods. To measure wind speed, a common anemometer will be used.

### **13.1.7 Access Platform**

Access to the test model is enhanced through the placement of a platform or dock extending along the length of the test area (Figure 2.11). The platform gives access to the model and allows the pool to be divided into a 12.0 foot wide section (Figure 2.14). The

# SIDE EXTENSION SYSTEM

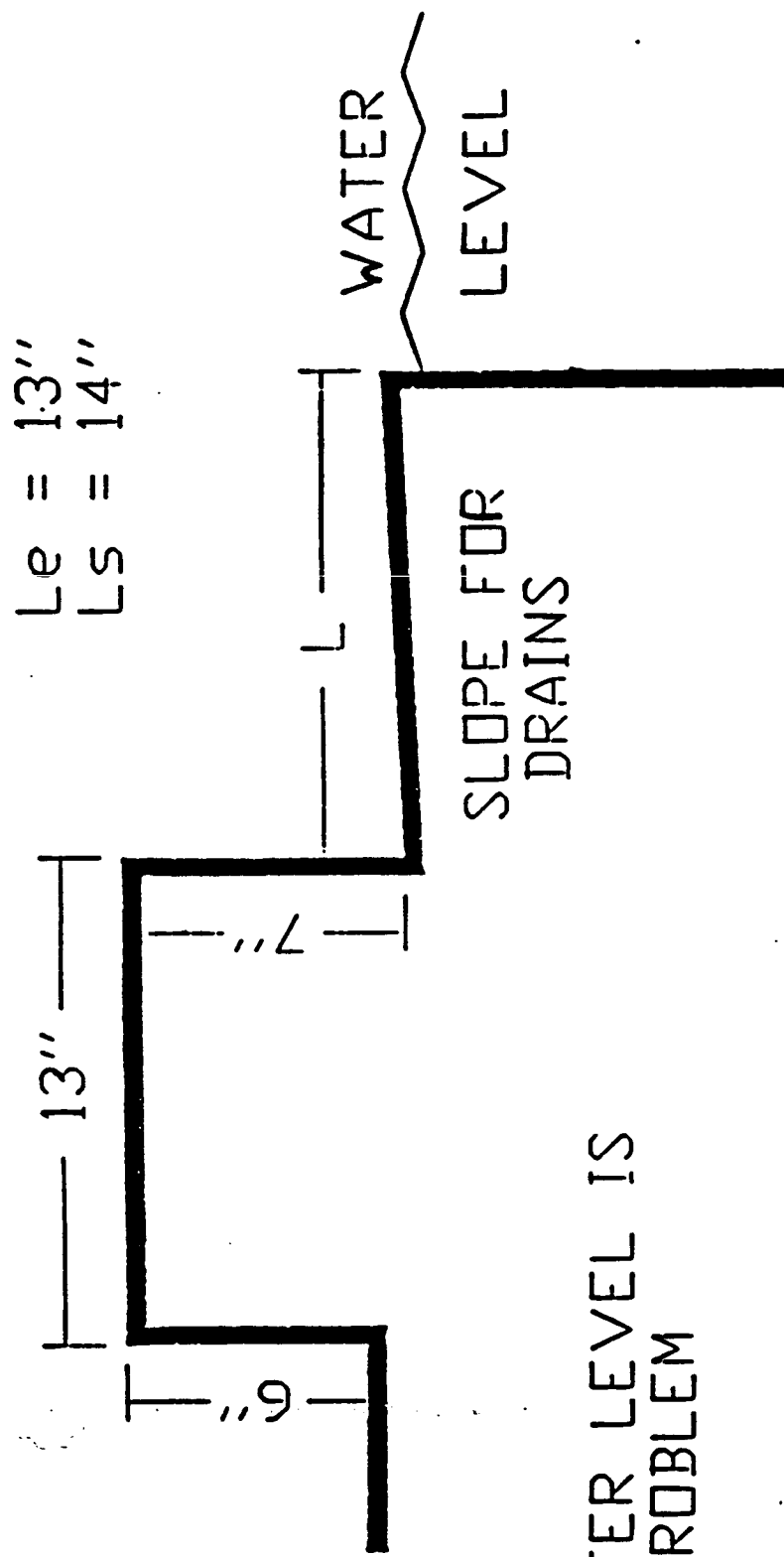


SIDE EXTENSIONS NECESSARY  
SO WATER LEVEL DOESNT  
HAVE TO BE CHANGED.

BRACKET MADE OUT OF METAL  
PLYWOOD WILL EXTEND SIDE  
OF POOL 12";

## FIGURE 2.9

# POOL EDGE SYSTEM



WATER LEVEL IS  
A PROBLEM

FIGURE 2.10

# UCF POOL FLOOR PLAN

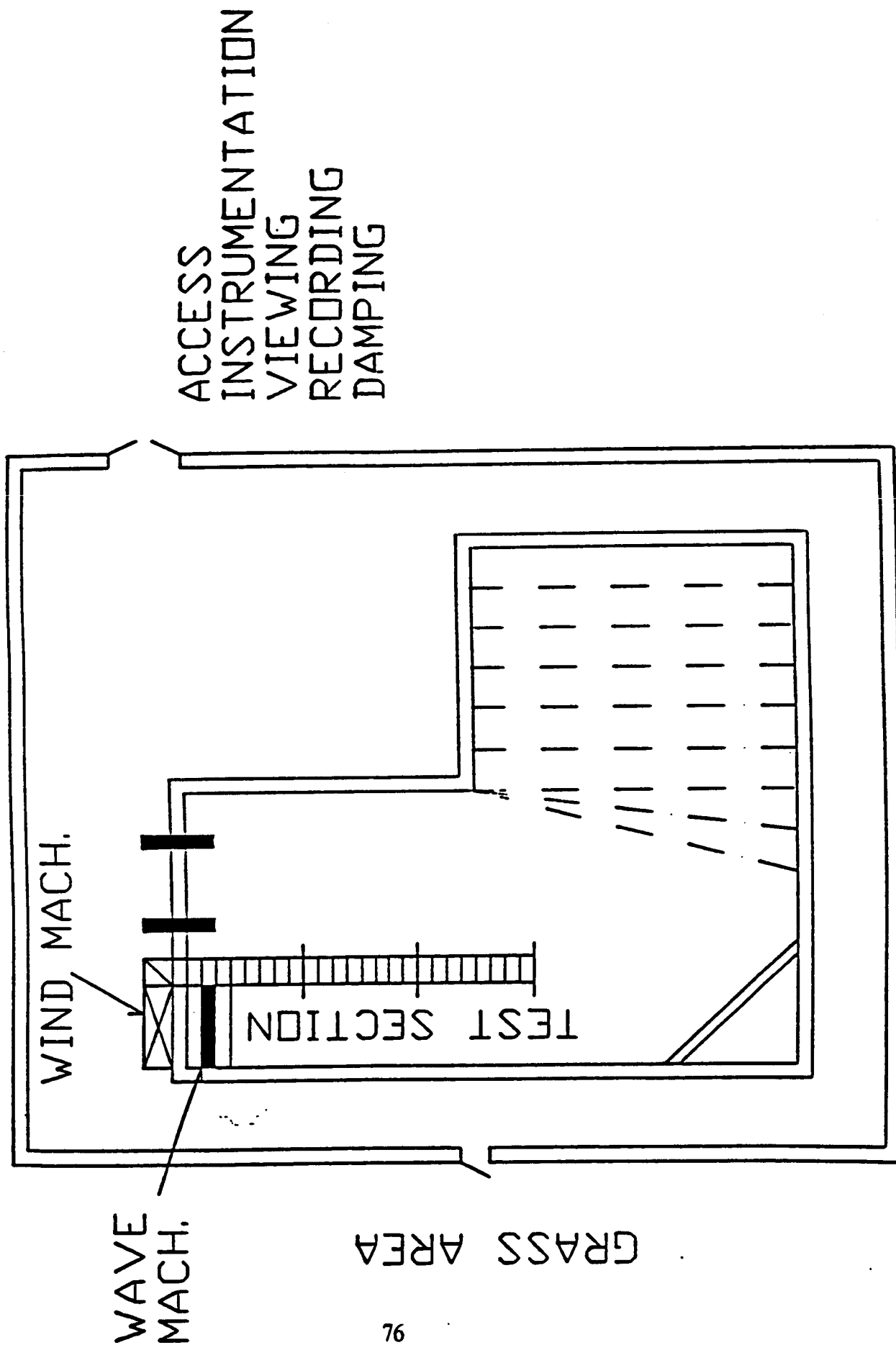


FIGURE 2.11

## ACCELEROMETER SYSTEM

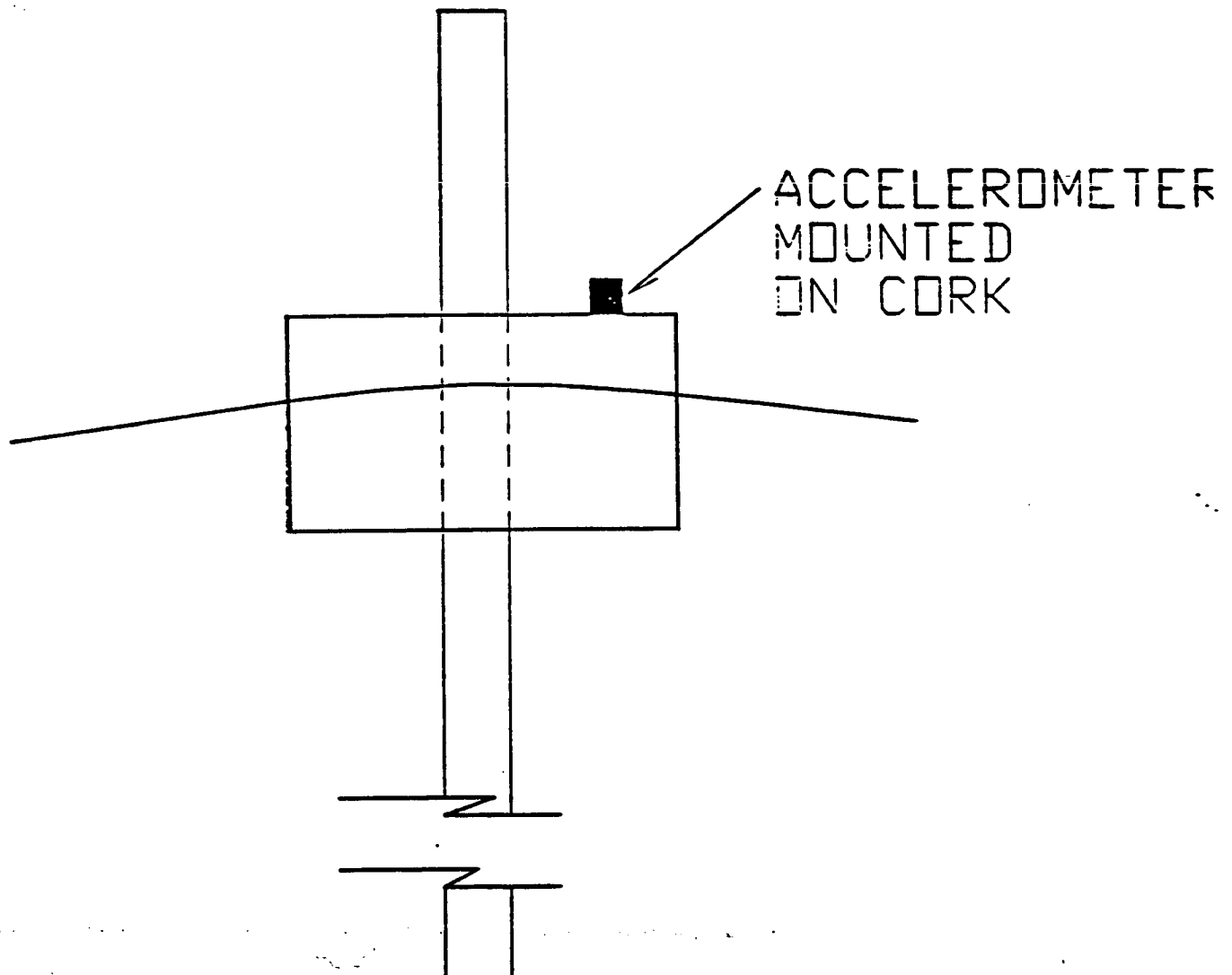


FIGURE 2.12

## CORK SYSTEM

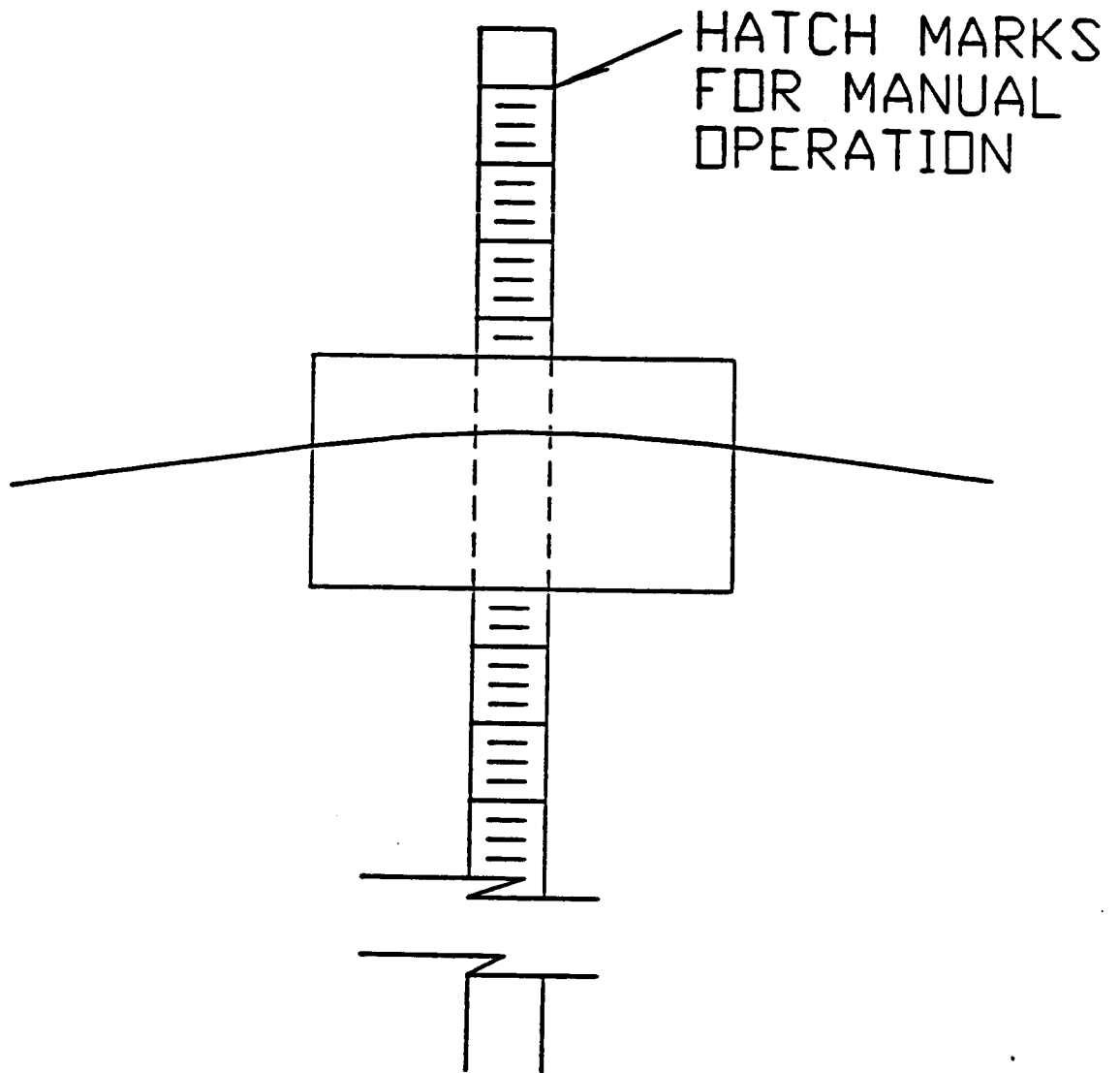
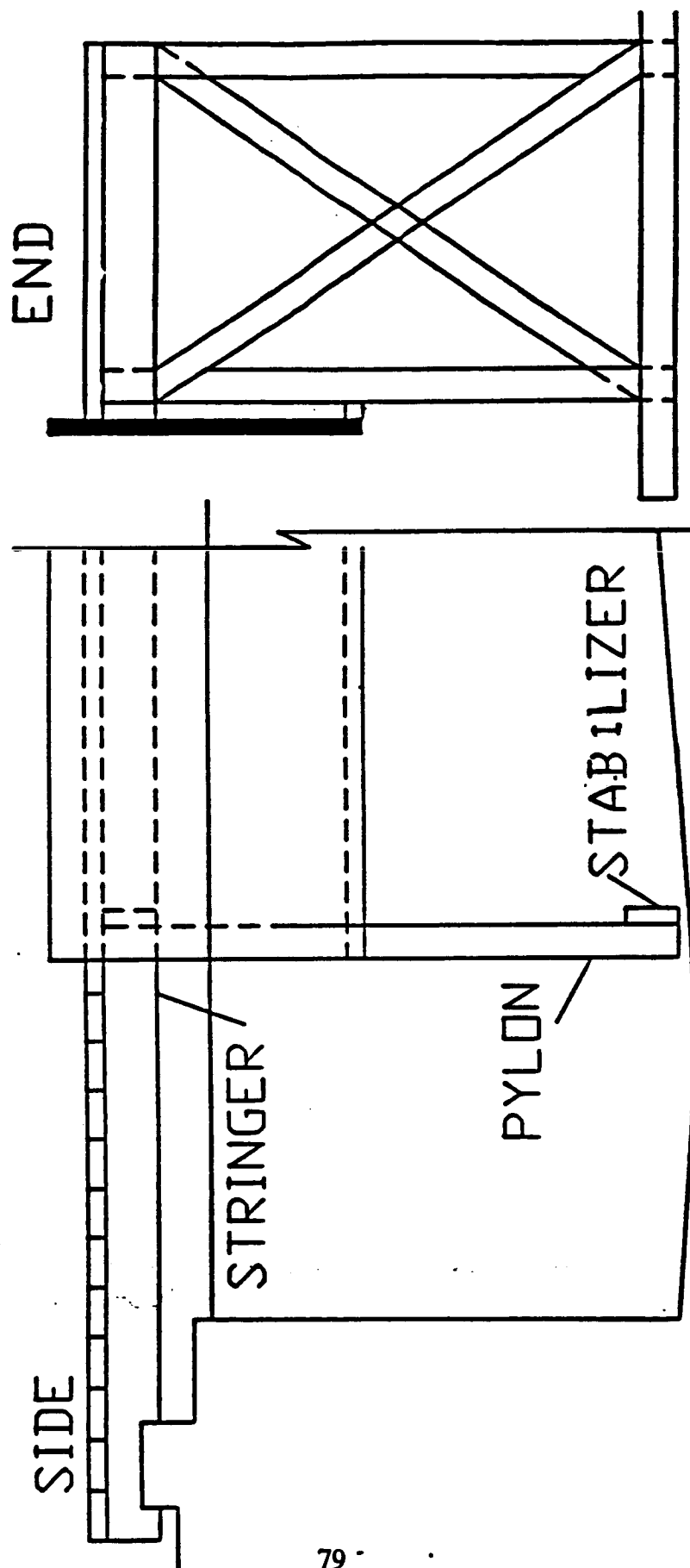


FIGURE 2.13



## DOCK SYSTEM



SYSTEM RESTS ON BOTTOM  
PLYWOOD HELPS PREVENT TWISTING FORWARD

FIGURE 2.14

plywood splash guard is incorporated into the platform to allow maximum wave heights over the entire test section. This platform is 3.0 ft wide and 10.0 ft long. It is built out of pressure treated wood. One end is fastened to the pool wall and the entire structure rests on the floor of the pool.

#### 13.1.8 Hoist

A hoist or winching device is being considered to provide for easy movement of the test model into and out of the test area. This system is capable of lifting a 150 pound object to a height of 15.0 feet. An A-frame structure stretching between the access platform and the pool edge containing an electric winch or manually operated pulley is being considered (Figure 2.15).

### 13.2 Permanent Facility

Another alternative to the construction of a portable WTF is building a permanent facility at UCF. This facility may be incorporated into the proposed CEBA III building design [13]. Two tank plans are introduced in this section. Both designs use off-the-shelf wind and wave generation equipment. MTS System Corporation is being considered as a possible supplier of the wave machine. Wind equipment from a number of sources is also being considered at this time.

Tank Plan #1 (Figure 2.16) has a sloped tank design which absorbs wave energy and provides damping. This plan is designed to accommodate the 3.0 foot diameter ACRV model and its support systems. The dimensions are: 100 x 12 x 13 feet.

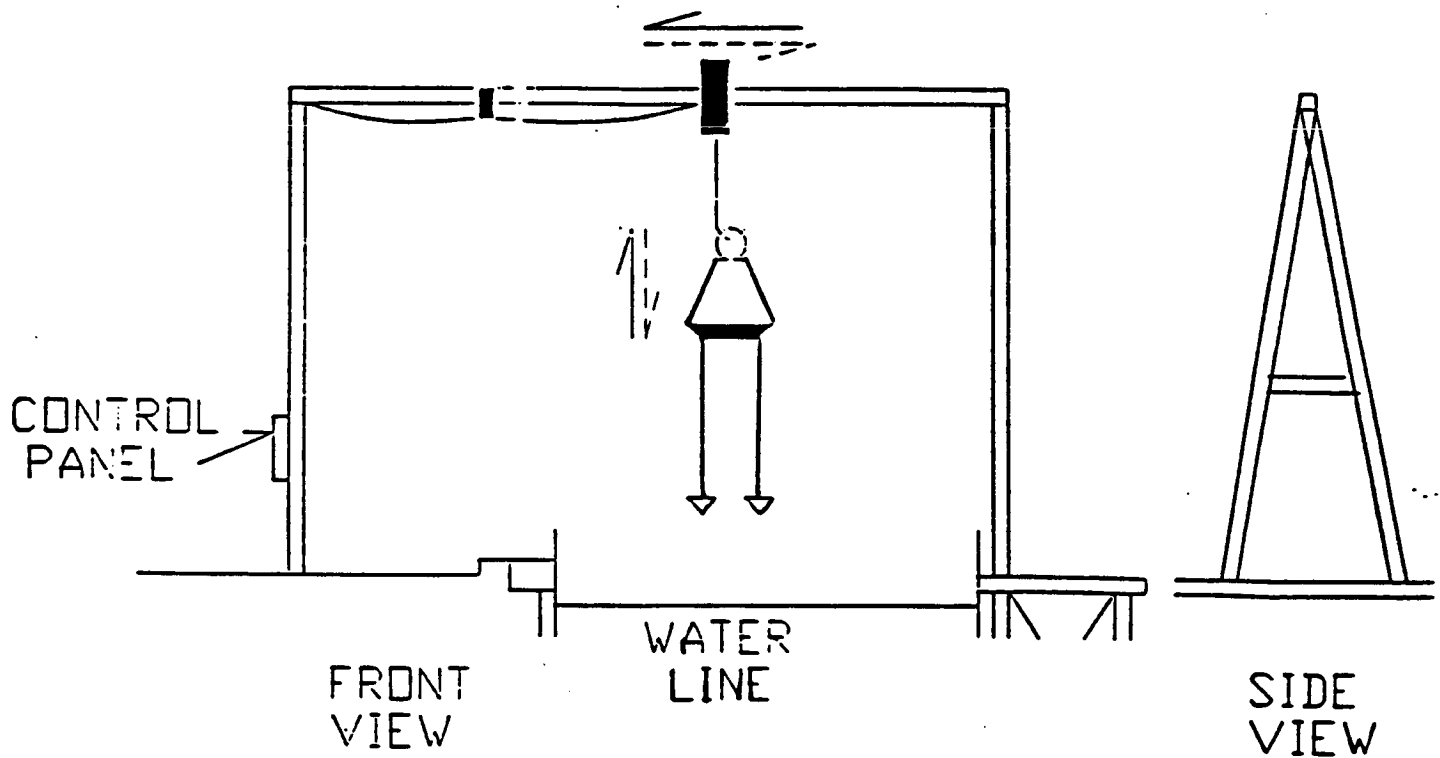
Tank Plan #2 (Figure 2.17) is a modification of Plan 1. This plan incorporates a vertical wall instead of an inclined wall. In this configuration, the WTF can be easily set up as a multi-purpose water tank. This straight walled tank can be altered to be a water tunnel using a variable speed pump system and may also have towing capability (Figure 2.18).

In either plan, tank height requires either a recessed placement into the floor or an extended ceiling. The costs involved in the construction of this type of facility are being examined. It is expected that the cost will be high when compared to the building of a portable system, but benefits should be great.

### 13.3 Summary

Research of existing WTF's, as well as considering design options for the construction of a permanent facility, has been completed. Existing facilities have been

# HOIST SYSTEM



THIS SYSTEM CAN BE MANUAL  
OR MOTORIZED.

**FIGURE 2.15**

# PLAN #1

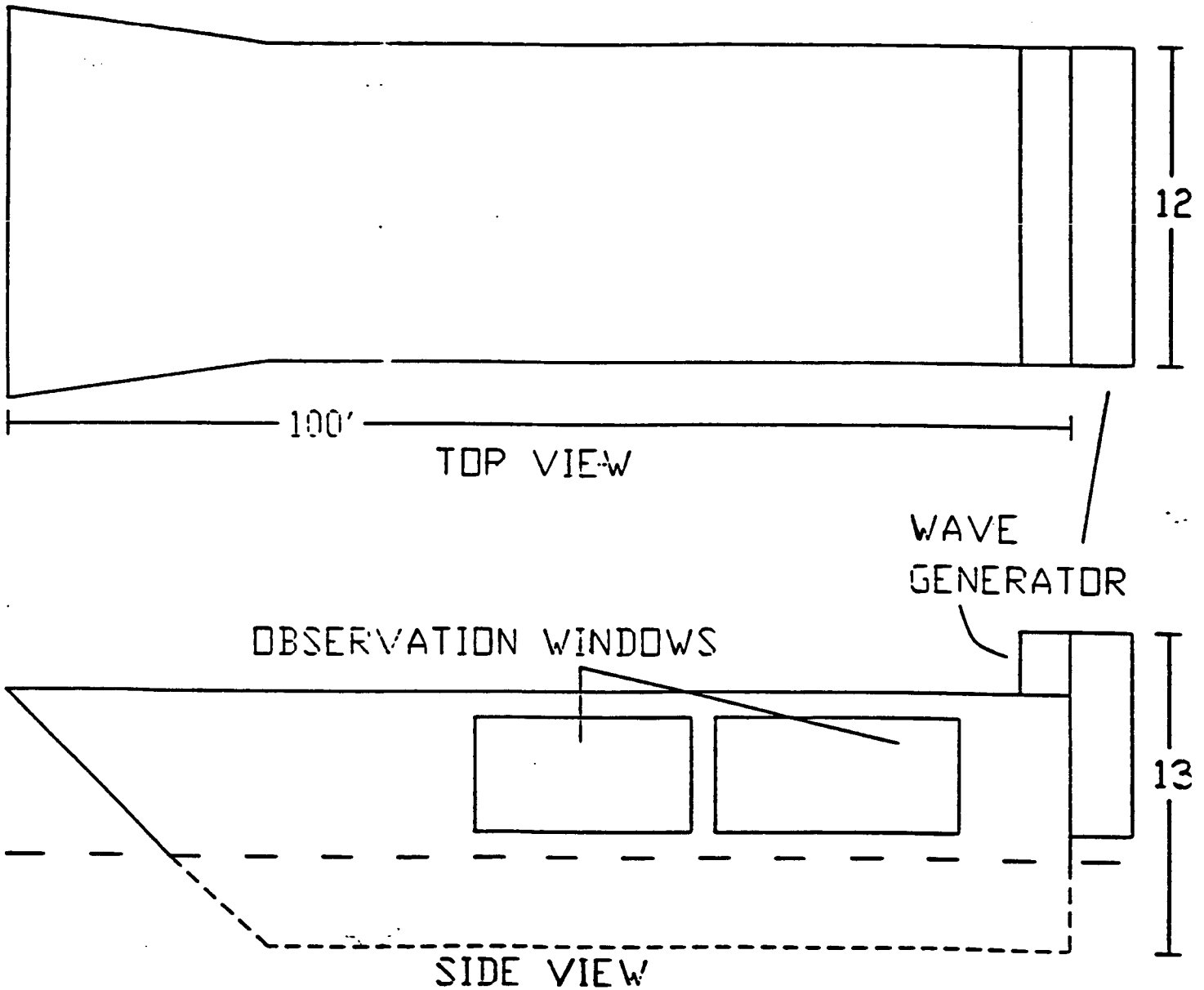


FIGURE 2.16

## PLAN #2

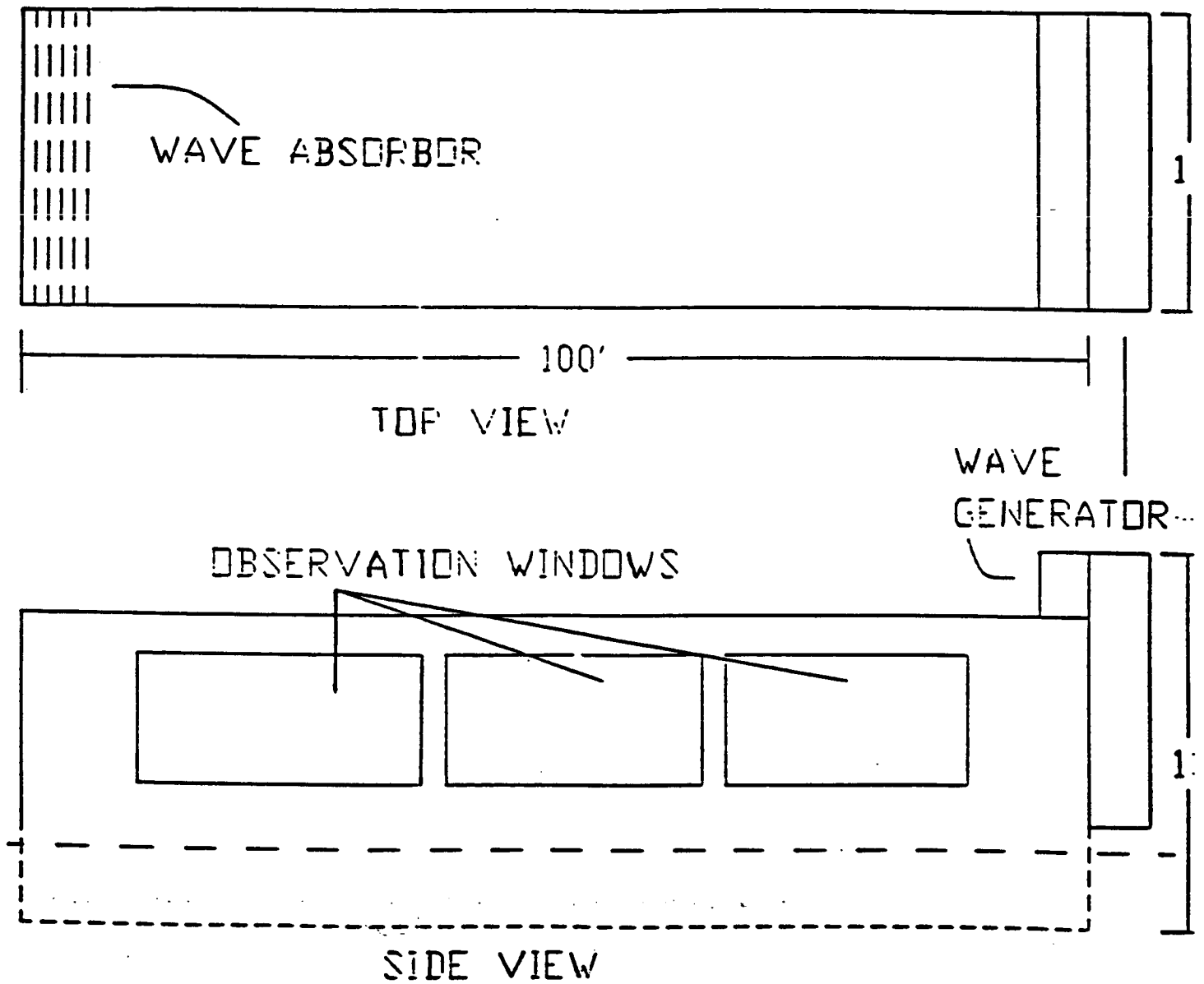


FIGURE 2.17

## PLAN #3

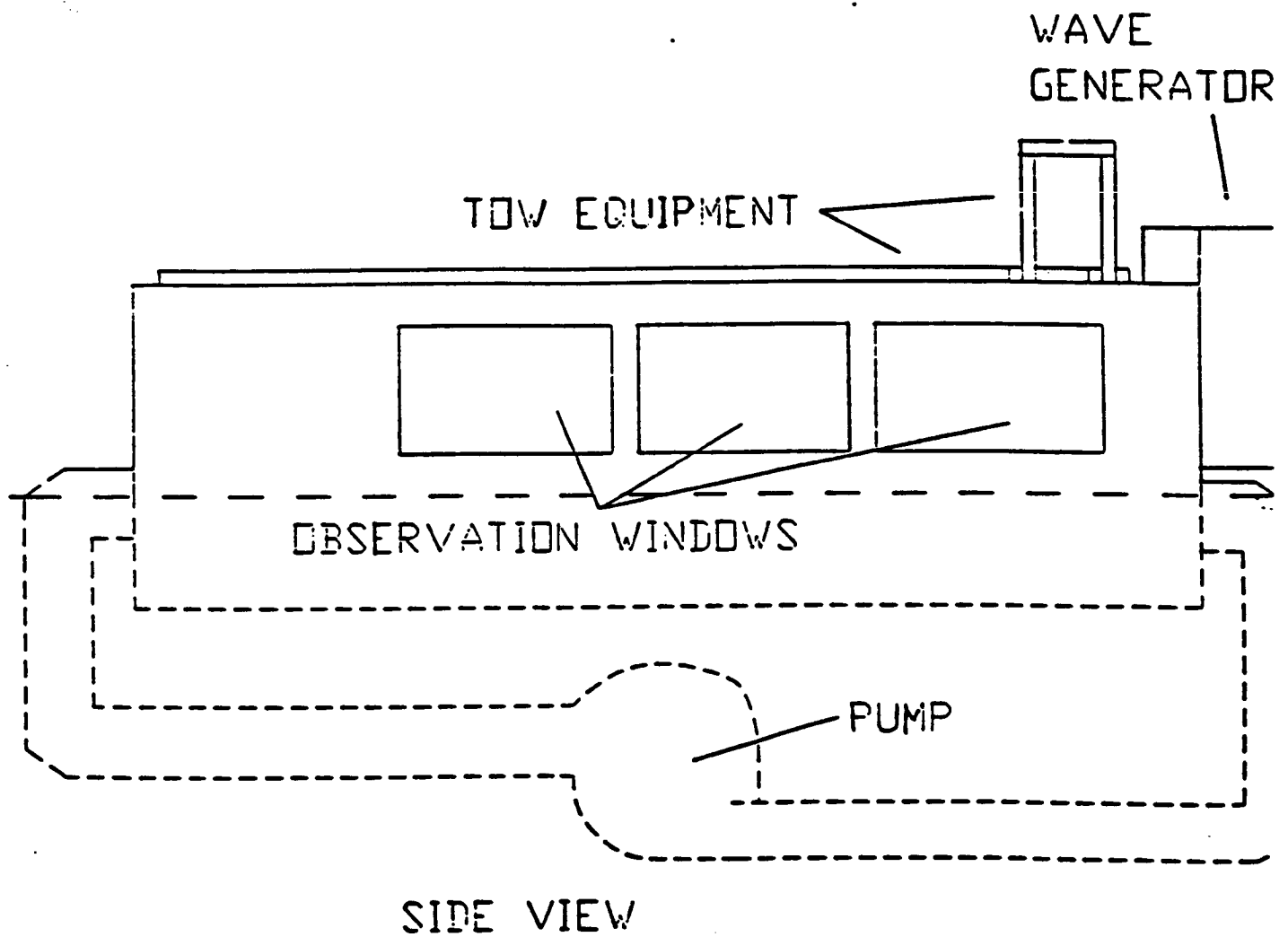


FIGURE 2.18

narrowed to include five sites: Davidson Laboratory, O.H. Hinsdale Wave Research Laboratory, Coastal Engineering Research Center, Offshore Technology Research Center and the University of Florida.

Possibilities for the construction of a local facility include the fitting of an existing swimming pool with sea state generation apparatus or the design and assembly of a self-contained permanent test site.

#### **Chapter 14.0 OPTIMAL SOLUTION - WATER TEST FACILITY**

This section presents the chosen optimal designs for the Water Test Facility Identification effort. The chosen alternatives are presented in this section including the criteria on which the decisions were based. Decision Matrices 2.1 - 2.2 (Appendix H) were formulated to aid in the decisions. Three options were considered in this effort:

1. Construct a portable wave facility.
2. Construct a permanent facility at UCF.
3. Use an existing facility.

Designs for a portable wave facility to be incorporated into a lake or swimming pool were considered. The swimming pool provides better qualities than that of a lake as a water source. The use of a swimming pool offers several distinct advantages. The UCF pool is an ideal location. Dimensions of the pool are suitable for testing in all configurations. Cost of modification of an existing pool will be less than that for the construction of a permanent facility. Because of its location, the UCF pool offers opportunities for retesting. Disadvantages with the use of this option include: damage to the pool area due to high oscillatory stress loads on side walls from machinery [12], time required for modification, and availability problems due to other scheduled pool activities.

The next option considered was the design and construction of a permanent WTF here at UCF. Advantages to this approach include: the tank can be designed in any size needed for testing purposes, the location on the UCF campus is ideal, and the facility will be available at any time for retesting. The disadvantage in the selection of this option is the high cost of construction.

The final option is the use of an existing WTF. The WTF's considered include: University of Florida's Coastal Engineering Department, Coastal Engineering Research Center in Vicksburg, Mississippi, Davidson Laboratory at Steven's Institute of Technology in Hoboken, New Jersey, Offshore Technology Research Center, at Texas A&M University in College Station, Texas, and O.H. Hinsdale Wave Research Laboratory at Oregon State University in Corvallis, Oregon.

O. H. Hinsdale Wave Research Laboratory satisfies a majority of the requirements needed for testing. The facility is available during the month of April. The dimensions of the wave pool (342 x 12 x 15 feet) supports testing of the ACRV model in all configurations. Regular and irregular waves of periods from 1.0 to 10.0 seconds and wave heights up to 5.0 feet can be generated in the wave pool. A moveable carriage equipped with a platform and one 5.0 ton hoist allow for moving the model in and out of the water. Visual records can be made using two underwater video cameras and a video camera located in the elevated control room. Instrumentation such as accelerometers can be connected to a computerized data acquisition system. O. H. Hinsdale WRL is a well established, self supporting university facility with a full-time staff of Ocean Engineers available for setup and testing.

A disadvantage of using O. H. Hinsdale WRL as a test facility is cost. Testing fees total \$15,000 for five days of testing. Transportation of people and cargo from Orlando to the testing facility is anticipated to be \$6,000. Lodging and food expenses are approximated at \$3,400. Incidental expenses of \$500 also need to be included. The total estimated cost for the testing is \$25,000.

#### Chapter 15.0 OBSERVATIONS AND RECOMMENDATIONS

Building a permanent water test facility at UCF is a positive step for the University in terms of attracting research dollars and should continue to be investigated. However, for this project it is not a feasible alternative. A portable wave facility to be installed in the UCF pool is a feasible alternative, but it is not possible to overcome the disadvantages previously mentioned. Therefore, it is recommended that an existing facility (O. H. Hinsdale Wave Research Laboratory) be used to perform the test on the ACRV model.



### **SECTION III.**

#### **ACRV RAPID EGRESS SYSTEMS**

##### **DESIGN PHASE**

- \* LIFT MECHANISMS
- \* EXTENSION SUPPORT MECHANISM
- \* RESTRAINT MECHANISMS

##### **BUILDING PHASE**

- \* LIFT MECHANISM CONSTRUCTION SCHEDULE
- \* EXTENSION MECHANISM CONSTRUCTION SCHEDULE
- \* RESTRAINT MECHANISM CONSTRUCTION SCHEDULE

##### **TESTING PHASE**

- \* TEST PLAN
- \* TEST RESULTS



### **SECTION III. ACRV RAPID EGRESS SYSTEMS**

#### **INTRODUCTION**

The Rapid Egress System facilitates the rapid and safe removal of a critically injured crewmember from the ACRV following splashdown. The objective of this design team is to design, build and test a one-fifth scale working model of the Rapid Egress System (RES) [14]. Concepts associated with the ACRV Rapid Egress System are presented in the design phase portion of this section. Work schedules and milestone charts are presented in the building phase portion and the test plan and results are detailed in the testing phase portion. The primary subsystems of the RES model considered are introduced below.

##### **Lift and Drive Mechanism**

The primary purpose for the lift and drive mechanism is to provide the motion required to deliver an injured crew member confined to an Emergency Egress Couch (EEC) from the center of the ACRV floor to the hatch location.

##### **Extension Support Mechanism**

The extension support mechanism provides the motion and support required to move the couch through the hatch to a specified horizontal distance away from the ACRV. This mechanism eliminates the need for an extending hatch.

##### **Restraint Mechanism**

The RES subsystems must be restrained at three separate stages. The lift mechanism must be restrained in the stowed position up to the time of deployment. The ESM must be locked to the lift mechanism when the couch is in the raised position. Prior to the couch being lifted off the platform, the EEC must be locked to the couch support platform.

### **DESIGN PHASE - ACRV RAPID EGRESS SYSTEMS**

The following discussion summarizes the current designs of the lift mechanisms, the extension support mechanism, and the restraint mechanisms. These designs are discussed in the following format:

- 16.0 Lift Mechanisms
  - 16.1 Four Link Injured Personnel Egress Mechanism (FLIPEM)
  - 16.2 Four Piston-Cylinder Mechanism (FPCM)
  - 16.3 Inclined Plane Mechanism (IPM)
  - 16.4 Roller Link Mechanism (RLM)
  - 16.5 Ironing Board Mechanism (IBM)
  - 16.6 Dual Scissor Jack Mechanism (DSJM)
- 17.0 Extension Support Mechanism
  - 17.1 Three Slider Support Mechanism (TSSM)
- 18.0 Restraint Mechanisms
  - 18.1 Cable/Lock
  - 18.2 Hook/Lock
  - 18.3 Latch/Lock

## Chapter 16.0 LIFT MECHANISMS

### 16.1 Four Link Injured Personnel Egress Mechanism (FLIPEM)

FLIPEM is a four bar linkage configured for double rocker operation. The two rocker links are of equal length and are connected to each other by the couch support platform (Figure 3.1). FLIPEM is powered by two compressed gas piston-cylinders. Each cylinder is pinned to the RES base and to the midpoint of a rocker link. When FLIPEM is locked and stowed, the gas in the piston-cylinder is in the state of highest compression. When the mechanism is released from the stowed position, the gas expands and extends the cylinder which causes the rocker link to lift the couch support.

Each rocker link incorporates a ratchet wheel that permits only clockwise rotation. Each ratchet is designed to support the entire load of FLIPEM should the other ratchet fail. The purpose of these ratchet wheels is to prevent the mechanism from falling in the event of a power system failure.

There are some disadvantages involved with the piston cylinder power system. Although small piston-cylinders are used in the copy machine industry, piston-cylinders of the desired dimensions could be difficult to locate. In addition, it is difficult to achieve simultaneous extension of multiple piston-cylinders. This could result in unacceptable lift motion. Unacceptable lift motion could also occur if the compressed gas leaks. However, FLIPEM can be powered in several other ways. For example, a sprocket can be incorporated in each of the ratchet wheels. These sprockets can then be driven by chains connected to a centrally located electric motor. This versatility and the overall simplicity of FLIPEM make it a good candidate for modeling.

## FOUR LINK INJURED PERSONNEL EGRESS MECHANISM

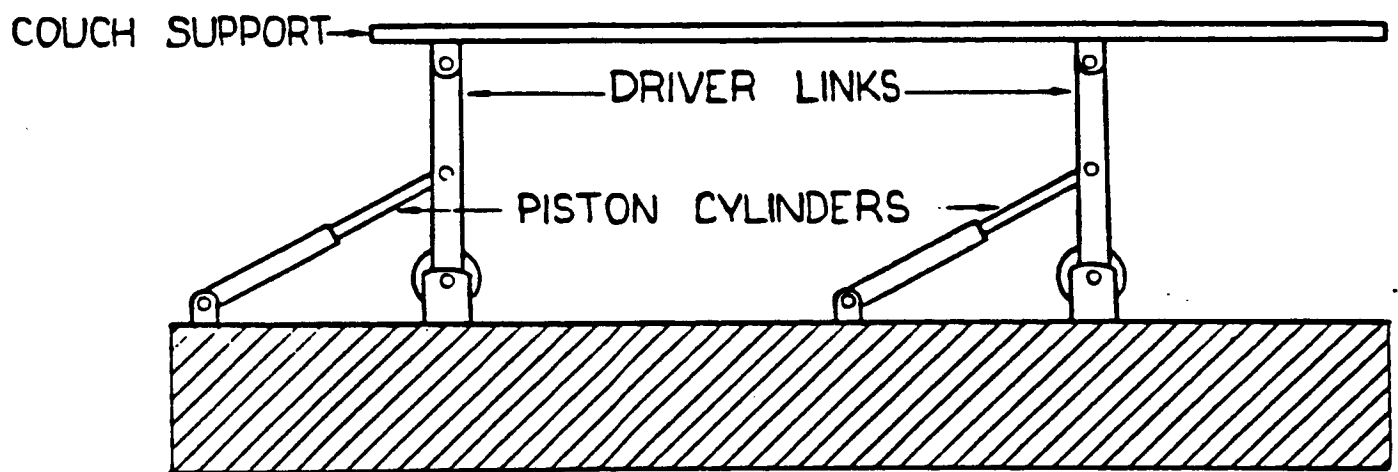


FIGURE 3.1

## 16.2 Four Piston Cylinder Mechanism (FPCM)

FPCM achieves vertical and horizontal displacement of the couch support platform. There are four separate compressed gas piston-cylinders attached to each of the four corners of the couch support platform. The opposite end of each cylinder is rigidly attached to the RES base at a prescribed angle (Figure 3.2).

In the stowed position, the FPCM is locked down with the piston-cylinders compressed. When the mechanism is released from the stowed position, the cylinders extend and raise the couch support platform to hatch level. Retracting the FPCM can be accomplished by manually opening release valves on each cylinder.

The FPCM is self-contained and needs no outside power supply. The system traverses the horizontal distance to the hatch as well as the vertical distance. The simplicity and self-contained nature of this design allow it to be modeled easily. However, the success of this modeling depends entirely on overcoming the inherent difficulties encountered with the piston-cylinder power system.

## 16.3 Inclined Plane Mechanism (IPM)

This design incorporates four fixed inclined tracks to direct the couch support platform to the hatch (Figure 3.3). The couch support platform is connected to these tracks by four rollers. Motion is provided by cables connected at the couch rollers and routed through the fixed tracks over pulleys to a drum under the couch. When rotating, the drum simultaneously pulls the lift cables and releases limiting cables. The limiting cables move in the tracks in the opposite direction of the lift cables and are connected to the same point on the couch as the lift cables. The purpose of the limiting cables is to restrict undesired motion of the couch caused by wave motion.

Production of the torque needed to raise the couch may be accomplished by a gear reduction mechanism in the drum. A similar mechanism is found on boat trailers. Using an electric motor as the primary power to drive the drum allows back-up power systems to be incorporated. The components of the IPM are easy to scale; therefore, this mechanism is simple to model. While fixed tracks provide direct motion to the hatch, they reduce accessibility to the EEC in the stowed position. Shock hazard introduced by using an electric motor in a wet environment may cause a problem, and cable routing could be complex.

## 16.4 Roller Link Mechanism (RLM)

The RLM consists of links connected to rollers that travel in channels located in the couch support platform and the base of the RES. Controlled power is provided to the RLM

## FOUR PISTON CYLINDER MECHANISM

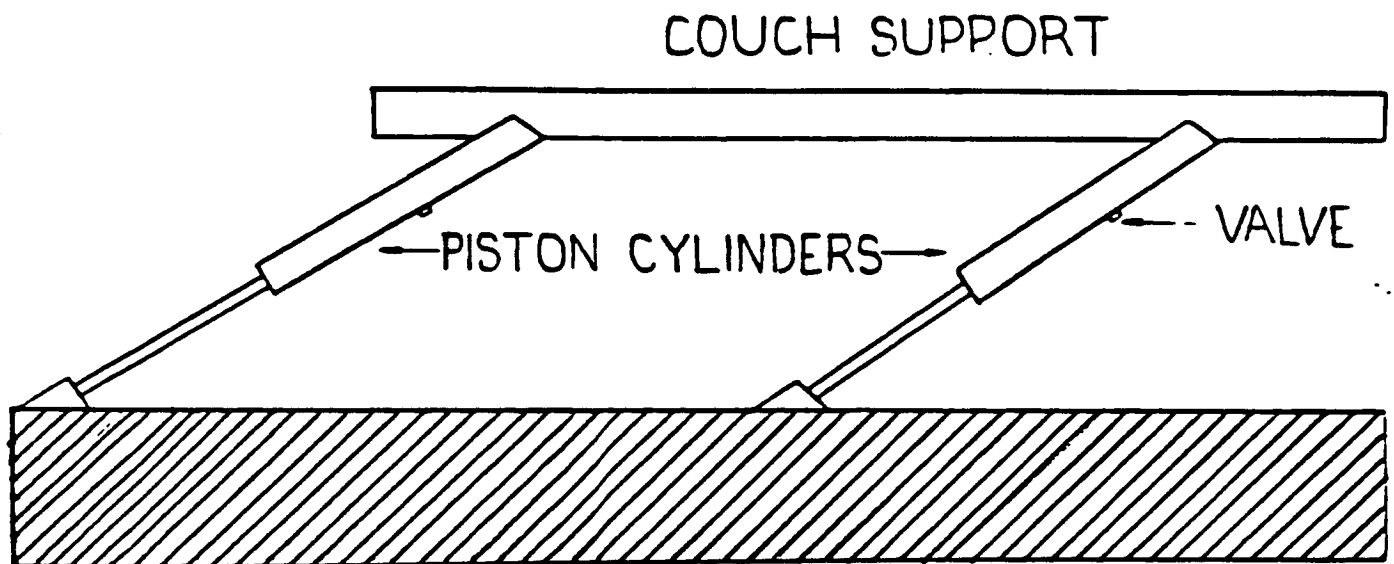


FIGURE 3.2

## INCLINED PLANE MECHANISM

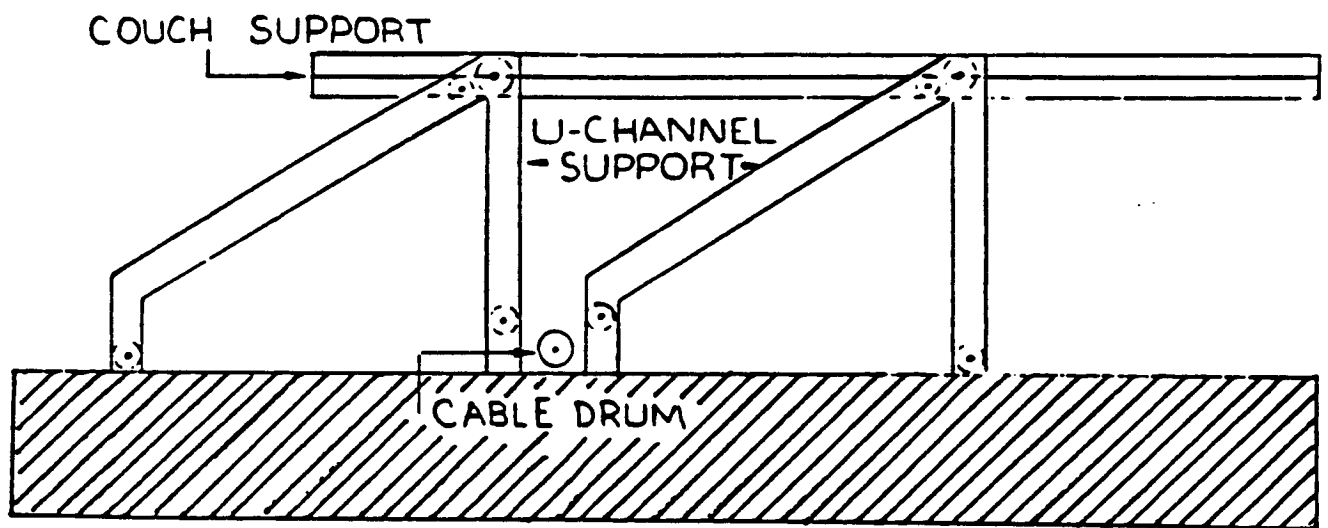


FIGURE 3.3



by a spring and damper system. The function of the damper is to regulate the lift velocity. A single assembly is formed by locating the damper within the radius of the spring. The spring-damper is pinned at a prescribed angle to the base and couch support platform (Figure 3.4).

When the RLM is released from the stowed position, the spring moves the couch support platform both horizontally and vertically. The base mounted rollers allow the entire apparatus partial horizontal movement, while the support mounted rollers provide the remaining horizontal motion.

The advantage of the RLM is the simplicity of the power system. Properly loaded springs will lose very little force, even when compressed for long periods of time. However, there are disadvantages to the RLM. The motion of this mechanism is unpredictable because external influences may cause the RLM to operate differently each time it is deployed. The general complexity of this design does not permit it to be modeled easily. In addition, a damper of proper dimensions may be difficult to locate.

#### 16.5 Ironing Board Mechanism (IRBM)

The IRBM uses springs and dampers to raise the couch support platform (Figure 3.5). One end of each spring is connected to the couch support platform. The opposite end is connected to a support leg. The legs rotate around a bearing pivot mounted on the RES base, and slide in a track mounted on the couch support platform. In the stowed position each spring is in its maximum stretched position. Vertical motion of the couch support platform is achieved by the force of the springs moving in the horizontal direction. Lift velocity is regulated by the use of a gas filled damper. Rigidity of the swing supports is accomplished by transverse links connecting the right and left sides of the support. The tracks include a one-way ratcheting mechanism to prevent retraction of the couch support platform during deployment.

Mounting the springs horizontally under the couch support platform reduces the height of the IRBM in the stowed position. This reduced height aids in complying with the space restriction of the ACRV. The widespread use of springs in industry demonstrates their reliability. All the components of IRBM can be easily fabricated to the dimensions necessary for a model. This fabrication provides good experience for the model builders and simplifies the acquisition of made-to-order parts. A disadvantage of the IRBM is that no power redundancy is provided.

## ROLLER LINK MECHANISM

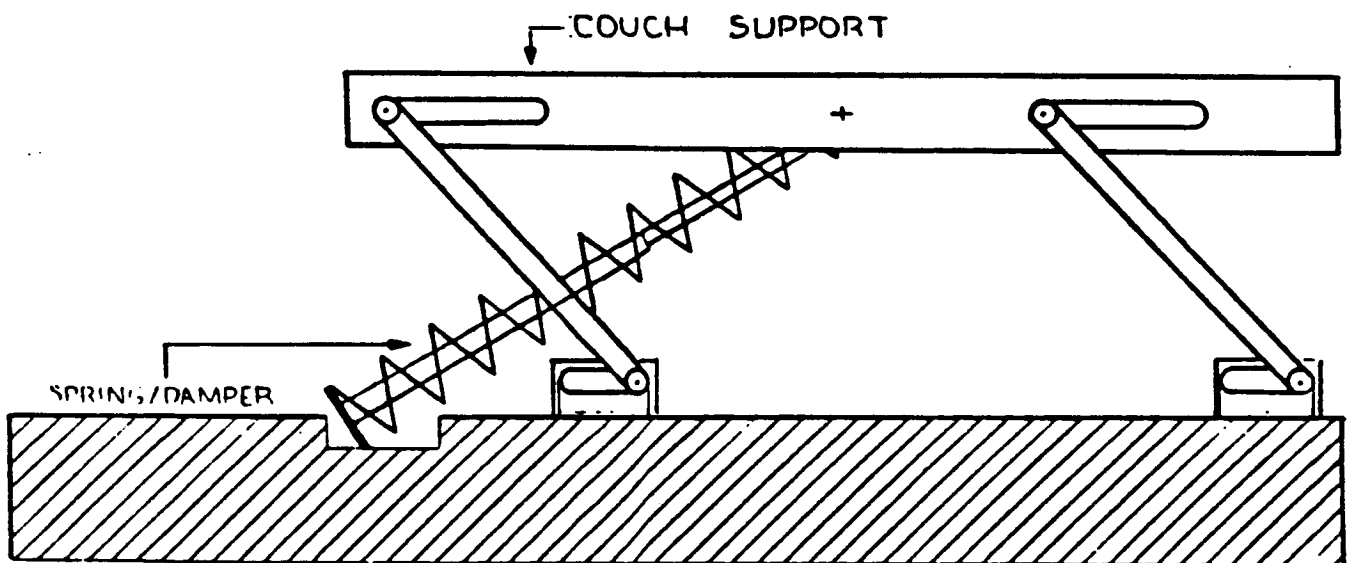


FIGURE 3.4

# IRONING BOARD MECHANISM

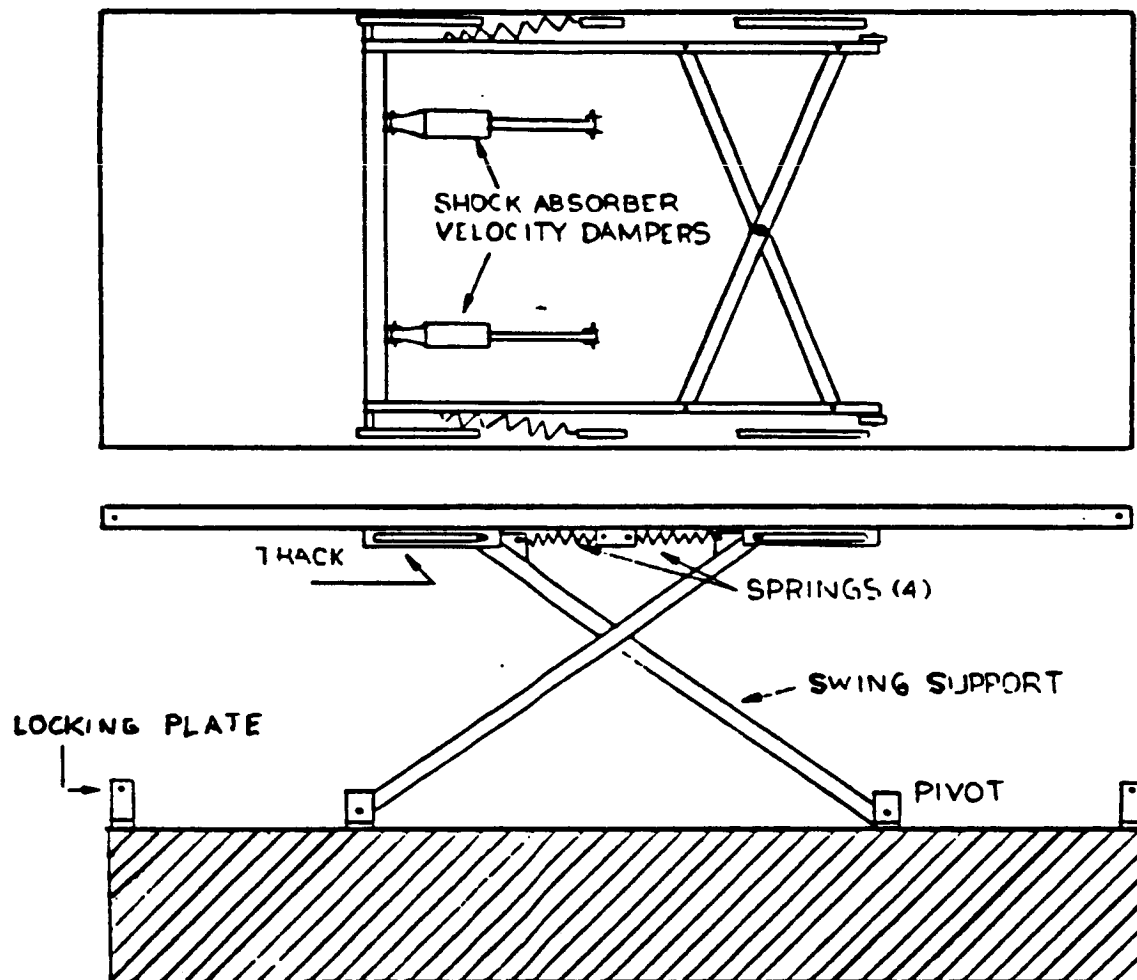


FIGURE 3.5

## **16.6 Dual Scissor Jack Mechanism (DSJM)**

The DSJM raises the couch support platform by using two scissor jacks (Figure 3.6a). These jacks are mounted rigidly to both the couch support platform and the base of the apparatus. Swing supports mounted at each end of the couch support platform provide additional stabilization. The bottom of the swing support will rotate about a bearing pivot mounted rigidly to the apparatus base. Integrated within the bearing pivot is a ratchet lock device to prevent retraction. The top of the swing supports slide in tracks mounted in the couch support platform. Rigid transverse links connect the right and left sides of the swing supports (Figure 3.6b).

The scissor jacks can be powered by several methods. One option is to use two electric motors, one mounted on each jack, connected to each other by a chain and sprocket. Another option would be the use of one motor to power both jacks. In the case of electric motor failure, back-up power may be achieved using a single hand crank attachment to the jacks. The main advantage of the DSJM is its simplicity and the ease with which it can be modeled. Scissor Jacks are dependable systems used everyday in the automobile industry. On the other hand, the potential shock hazard associated with using an electric motor in a wet environment is a disadvantage for the DSJM.

## **Chapter 17.0 EXTENSION SUPPORT MECHANISM**

### **17.1 Three Slider Support Mechanism (TSSM)**

Horizontal motion of the couch support platform from the raised position through the hatch is accomplished by the TSSM (Figure 3.7). The TSSM consists of a three stage track and roller configuration and a two piece couch support platform. The TSSM is located within the two piece couch support platform. Each stage moves the top half of the couch support platform one-third of the total horizontal motion, and is capable of supporting the weight of the EEC in any position. Additional support comes from extender attach points located on the bulkhead near the hatch and by the hatch itself. The TSSM can be driven by a rack and pinion using an electric motor and hand work, or by a pulley and cable assembly. Any powering method can be disconnected for manual extraction. The couch is attached to the stage three extender by a quick release mechanism for easy removal. After EEC removal, the entire TSSM can be released from the platform and thrown overboard, so the hatch can be re-secured. The primary advantage of the TSSM is that it eliminates the need for a complex extending hatch mechanism; however, it does not supply any redundancy of motion.

## DUAL SCISSOR JACK MECHANISM

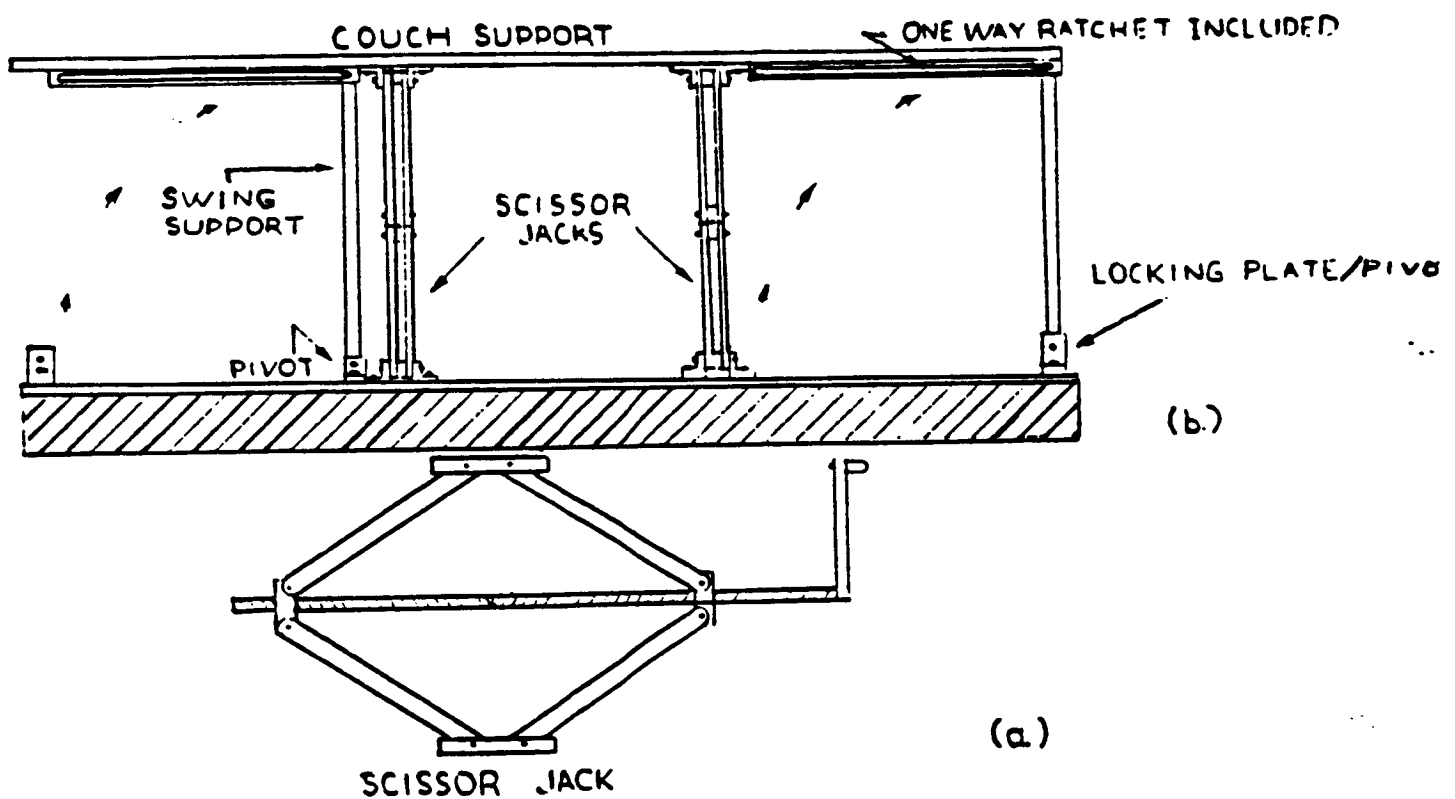


FIGURE 3.6

# THREE SLIDER SUPPORT MECHANISM

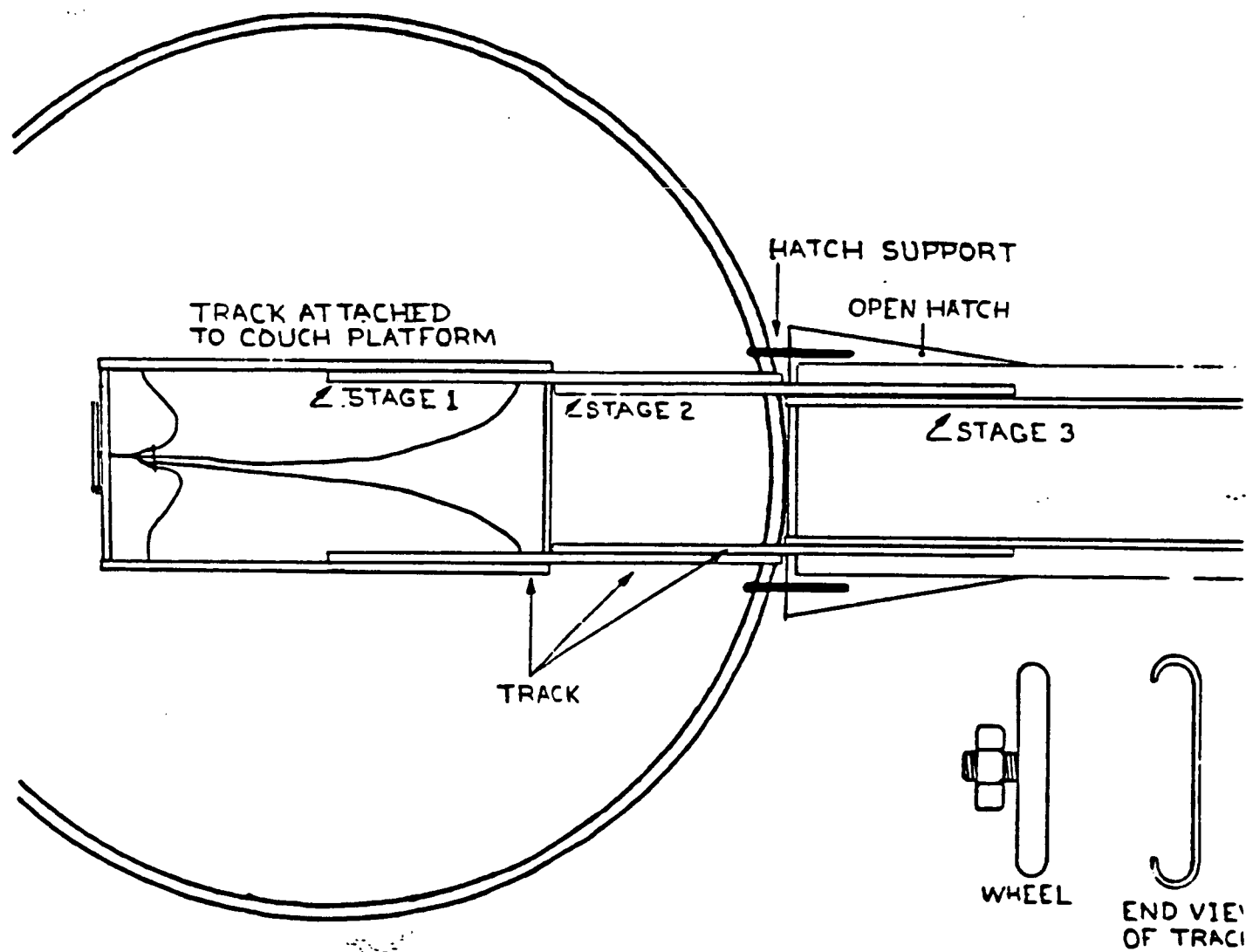


FIGURE 3.7

## **Chapter 18.0 RESTRAINT MECHANISMS**

### **18.1 Cable/Lock Mechanism**

The Cable/Lock mechanism consists of a cable connected on one end to a pin lock. The opposite end of the cable is connected to a release lever. When the Cable/Lock mechanism is in the latched position, the pin lock extends through a latch mechanism into a locking plate (Figure 3.8).

Activating the release lever retracts the cable. This motion pulls the pin lock from the locking plates and latch mechanism. Once the pin lock is disabled the system is no longer restrained. This design is simple and reliable and meets all three restraint needs of the RES. Cable technology has been used in bicycle brakes and gearing for many years. Using parts available through bicycle technology the Cable/Lock mechanism is easily modeled. The use of four pin locks provides lock redundancy. If one pin lock should fail, the RES will not be able to move freely. Although the Cable/Lock mechanism has lock redundancy, it does not have release redundancy. If the release lever fails, there is no way to disengage the pin locks. Lack of release redundancy is not an acceptable characteristic; therefore, further design is necessary.

### **18.2 Hook/Lock Mechanism**

The Hook/Lock Mechanism consists of two hook plates located at opposite ends of the couch support platform. A solid bar release lever connects the two hook plates together (Figure 3.9). When engaged, the hook plates lock in hook sockets in the bottom of the EEC. When the release lever is pulled, the hook plates disengage from the hook sockets allowing the EEC to be removed.

The Hook/Lock Mechanism is described as it would be configured to restrain the EEC to the couch support platform. However, simple adjustments to the orientation allow this mechanism to be used in all three restraint needs. Modeling this system is simple. The components can all be purchased at a hardware store and assembled to create the mechanism. The current configuration of the Hook/Lock Mechanism does not provide lock or release redundancy; therefore, further design is necessary.

### **18.3 Latch/Lock Mechanism**

The Latch/Lock mechanism is similar to the latch found on steamer trunks. The components are a lever, a hasp and a catch (Figure 3.10). When the lever is pulled, the hasp lifts above the catch and releases the restrained object.

## CABLE/LOCK MECHANISM

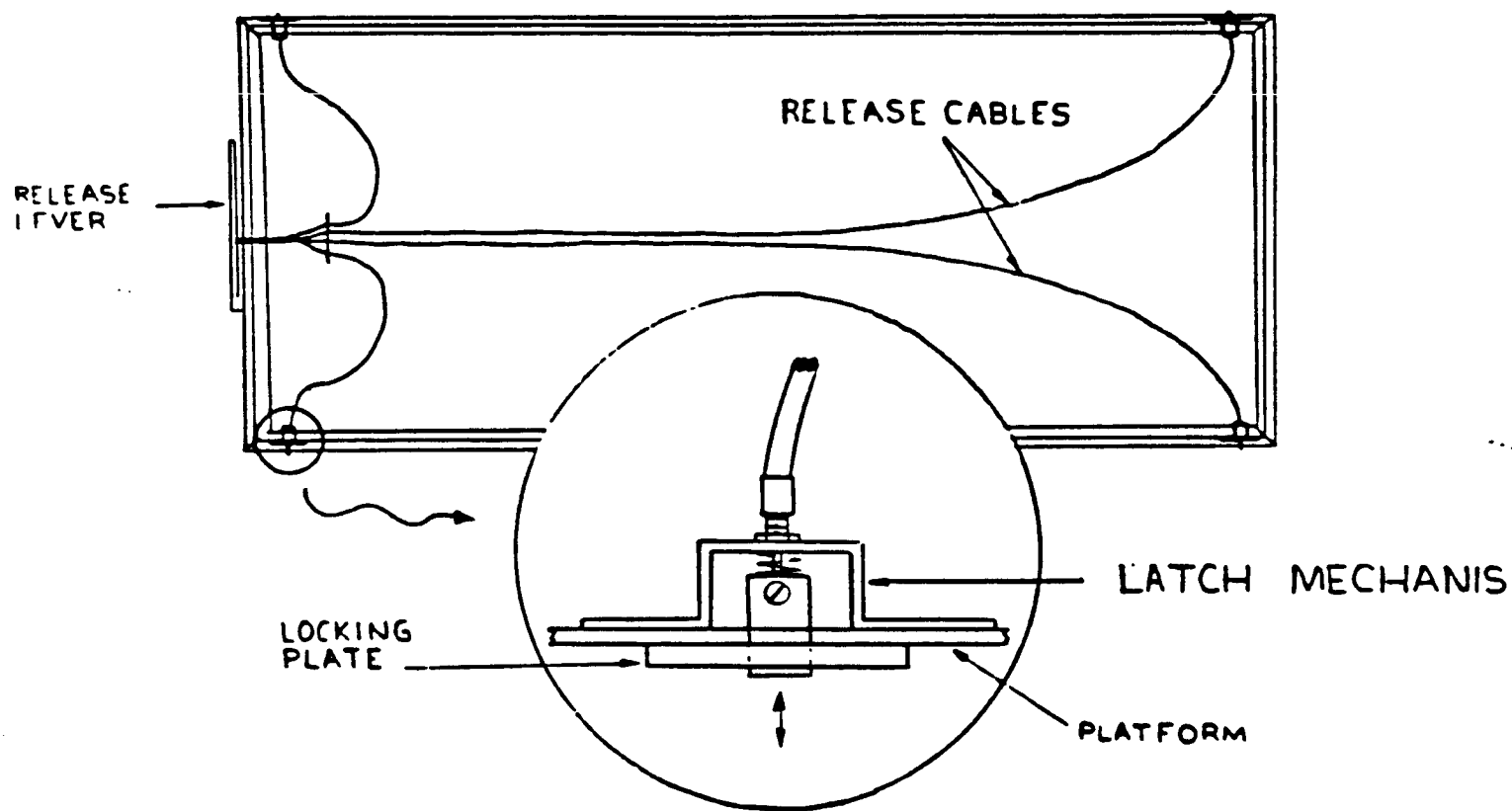


FIGURE 3.8



## HOOK/LOCK MECHANISM

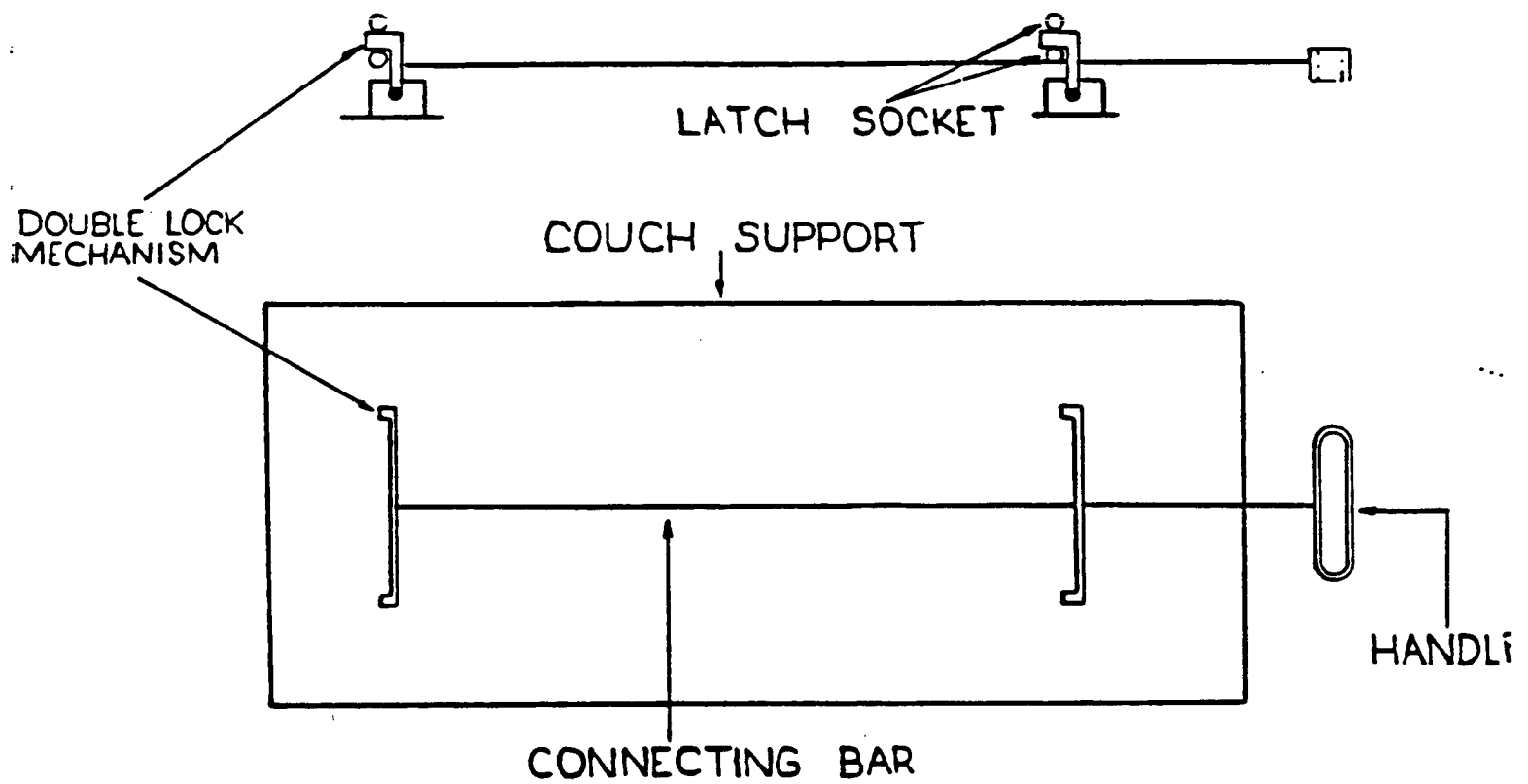


FIGURE 3.9

## LATCH/LOCK MECHANISM

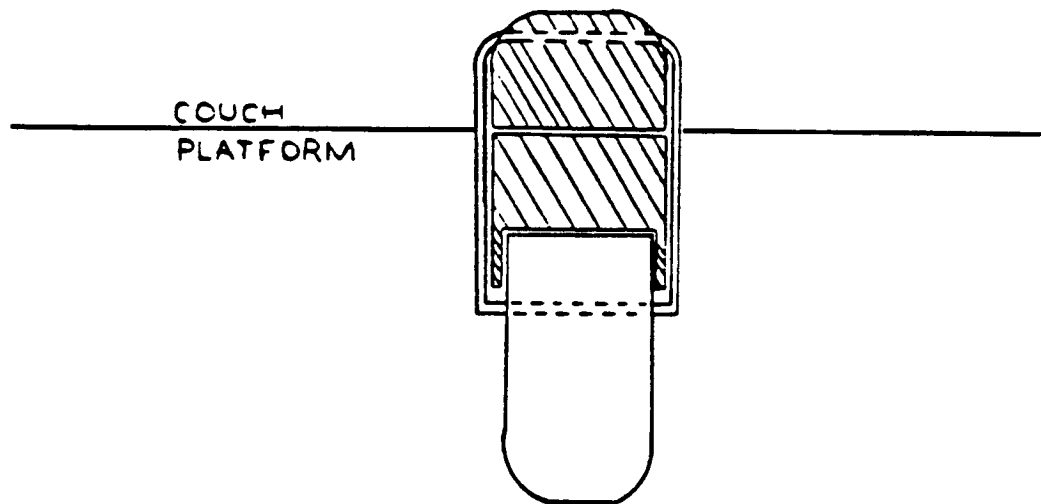


FIGURE 3.10

To provide the amount of restraint necessary, numerous Latch/Lock mechanisms are needed. Simultaneous release of these mechanisms is not possible. This could create a problem when releasing the EEC from the couch support platform. The Latch/Lock mechanism can be used to restrain all three restraint positions and does provide lock redundancy. The configuration of the Latch/Locks provides accessibility from the surface of the RES. This accessibility allows the lock to be manipulated in case of failure. The availability of Latch/Locks at a hardware store permits this system to be modeled easily.

## **CHAPTER 19.0 OPTIMAL SOLUTION - ACRV EGRESS**

This section presents the chosen optimal designs for the ACRV Rapid Egress Systems. Chosen alternatives are presented in this section, including the criteria on which the decisions are based. Decision matrices 3.1 - 3.3 (Appendix H) were formulated to aid in the decisions.

### **19.1 Lift Mechanism**

Lift mechanisms were evaluated by considering their performance of pre-determined requirements. The Four Link Injured Personnel Egress Mechanism (FLIPEM) is the optimal choice based on the requirements listed in the Lift Mechanism Decision Matrix 3.1 (Appendix H). FLIPEM is designed as a simple four bar linkage; therefore, it is dependable, easy to construct and maintain, and cost effective. FLIPEM has only one degree of freedom which allows the mechanism to be driven by a single input motion [15]. In the FLIPEM lift mechanism, two air piston cylinders provide power to the system. Each cylinder has the capability of lifting the mechanism. This design allows for one driving cylinder and one back up cylinder for power redundancy. Ease of operation and stability are inherent through the use of piston cylinders and a four bar linkage.

Two ground pin joints are spaced 10.8 inches apart and raised 1.5 inches off the floor on each side of the FLIPEM mechanism (Figure 3.11a). Rocker links, each 4.4 inches long, connect the ground pin joints to the couch support platform. The ground pin joints consist of a straight rod rigidly connecting the rocker links on each side of the FLIPEM mechanism (Figure 3.11b). In the lowered position the couch support platform is a vertical distance of 2.25 inches from the floor and a horizontal distance of 4.4 inches from the hatch.

When released, two gas cylinders located beneath the couch support platform moves the couch a vertical distance of 6.4 inches and a horizontal distance of 4.4 inches to the hatch (Appendix A). For the present configuration, forty pounds of force is required from the gas cylinder to initiate the motion of the couch [16]. Ratchets located in the ground pin joints ensure one way motion. These ratchets are released to allow manual retraction.

# FOUR LINK INJURED PERSONNEL EGRESS MECHANISM

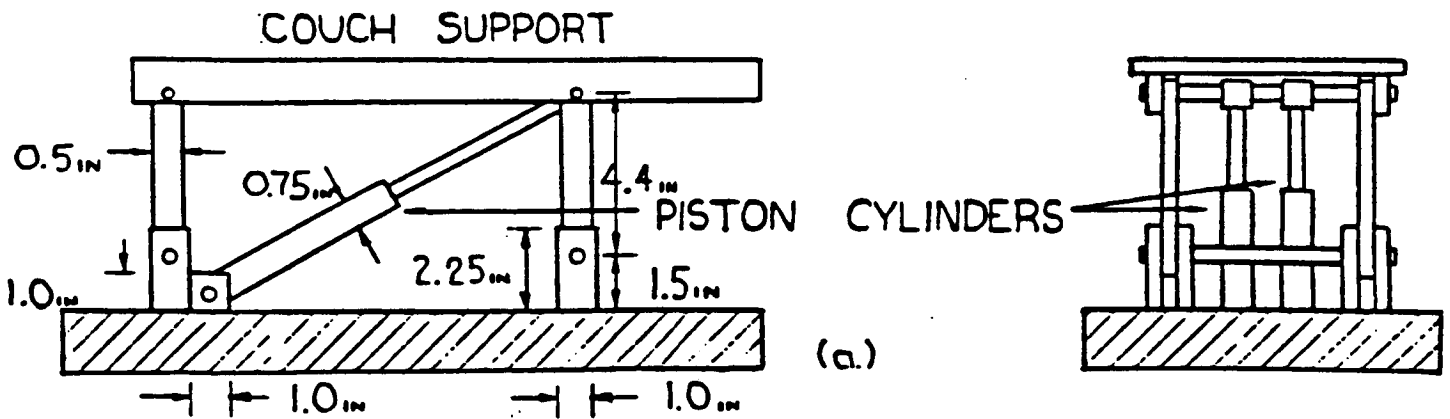
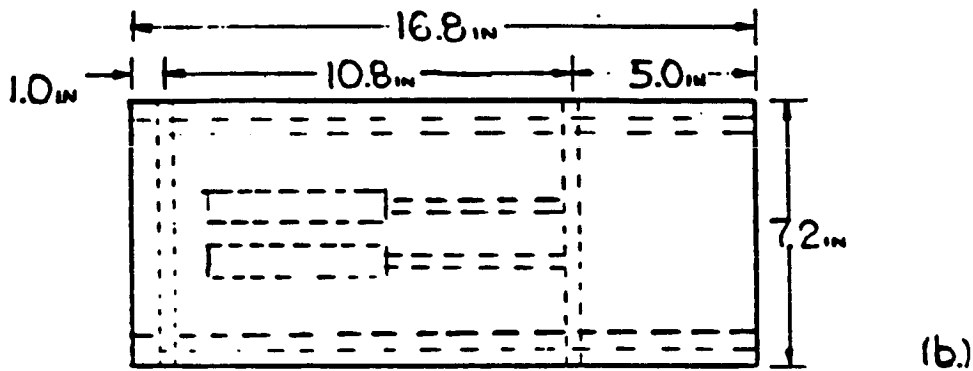


FIGURE 3.11

## 19.2 Extension Support Mechanism

The choice for the Extension Support Mechanism is the Three Slider Support Mechanism (TSSM) (Figure 3.12). The TSSM consists of two, three stage, track and roller sliders rigidly connected by the couch support platform. Each stage moves the couch support platform one-third of the total horizontal motion, and is capable of supporting the weight of the EEC in any position. The sliders used for the TSSM are similar to those used on tool box drawers and kitchen cabinets. Fully deployed, the TSSM extends 21.6 inches out of the hatch. Power for the TSSM is provided by a reversible electric motor and cable system. When the extension mechanism is in the unextended position the greatest amount of cable is deployed. As the motor rotates, the cable is pulled around pulley A and wound onto the spool. The decreasing length of deployed cable moves pulley B outward, providing deployment of stage 1. As the cable moves around pulley C, it forces pulley D to move outward. The motion of pulley D provides deployment of stage 2. As the cable moves around pulley E, it forces point F to move outward providing deployment of stage 3. Binding is prevented by a similar cable and pulley system mounted on the opposite side of the extension mechanism.

The TSSM is retracted by a separate cable attached to the couch support platform. The cable is wound around a spool in the direction opposite to that of the extension cables. As the extension cable is wound onto a spool, the retraction cable is released. To retract the TSSM, the direction of the motor is reversed. When the motor operates in reverse, the retraction cable is wound onto its spool while the extension cable is released from its spool. This cable system, for extension and retraction, restricts any undesired motion of the couch support platform. In addition, it provides the necessary restraint required to hold the TSSM in its retracted position.

## 19.3 Restraint Mechanisms

The choice of a suitable restraint mechanism is based on requirements similar to those of the lift mechanism. The most important requirement for the restraint mechanism is simplicity. A simple device provides dependability, feasibility, ease of operation, and low cost as inherent features. The restraint mechanism that satisfies these requirements is the Hook/Lock Mechanism.

FLIPEM is restrained to the floor before deployment by a single hook placed in an accessible position on the mechanism (Figure 3.13). The spring loaded hook rotates about a bolt and is compressed when in the locked position. A steel rod, powered by a solenoid, holds the hook in the locked position (Figure 3.14). When the solenoid is remotely energized, the rod retracts and releases the hook allowing FLIPEM to deploy.

# THREE SLIDER SUPPORT MECHANISM

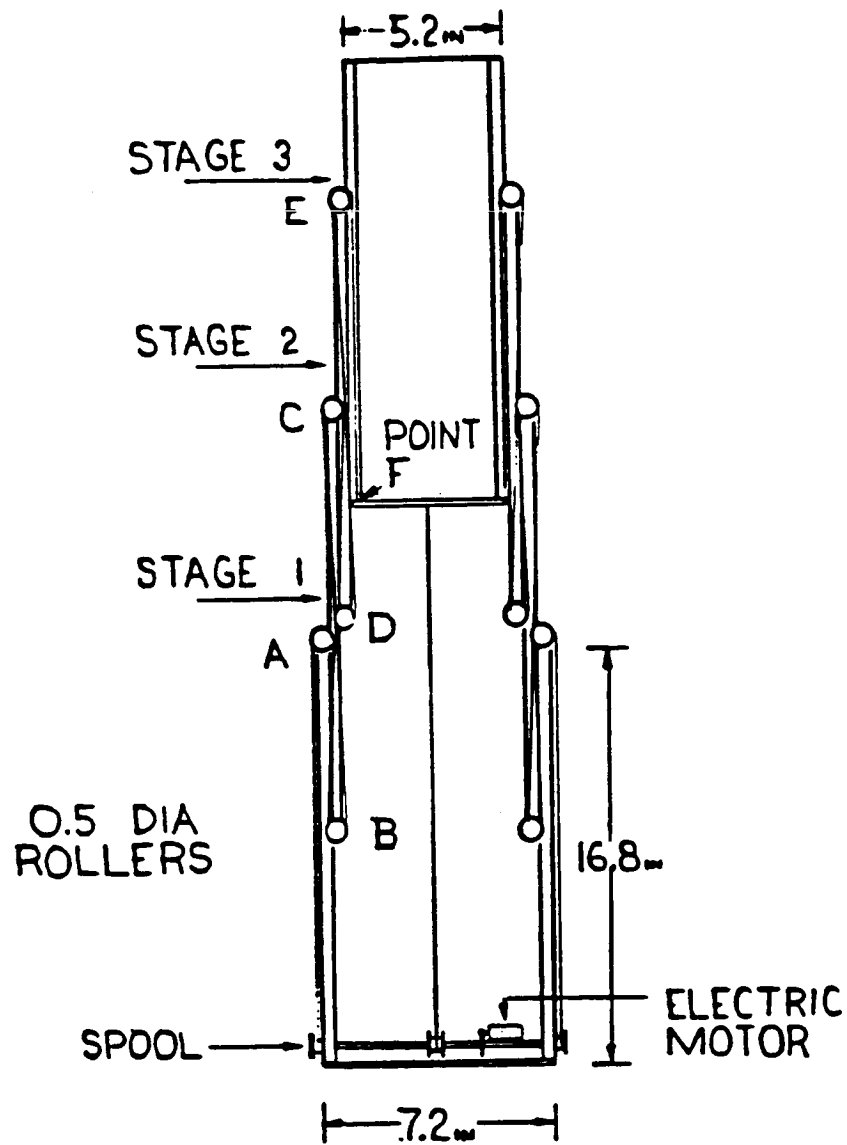


FIGURE 3.12

## FLIPEM RESTRAINT MECHANISM

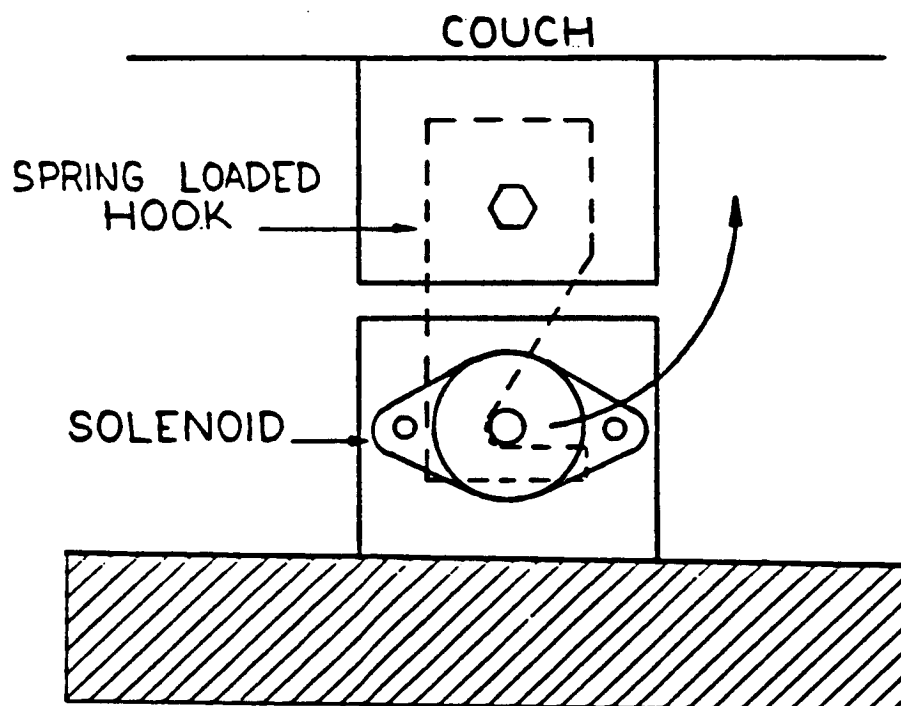


FIGURE 3.13

## SOLENOID AND HOOK

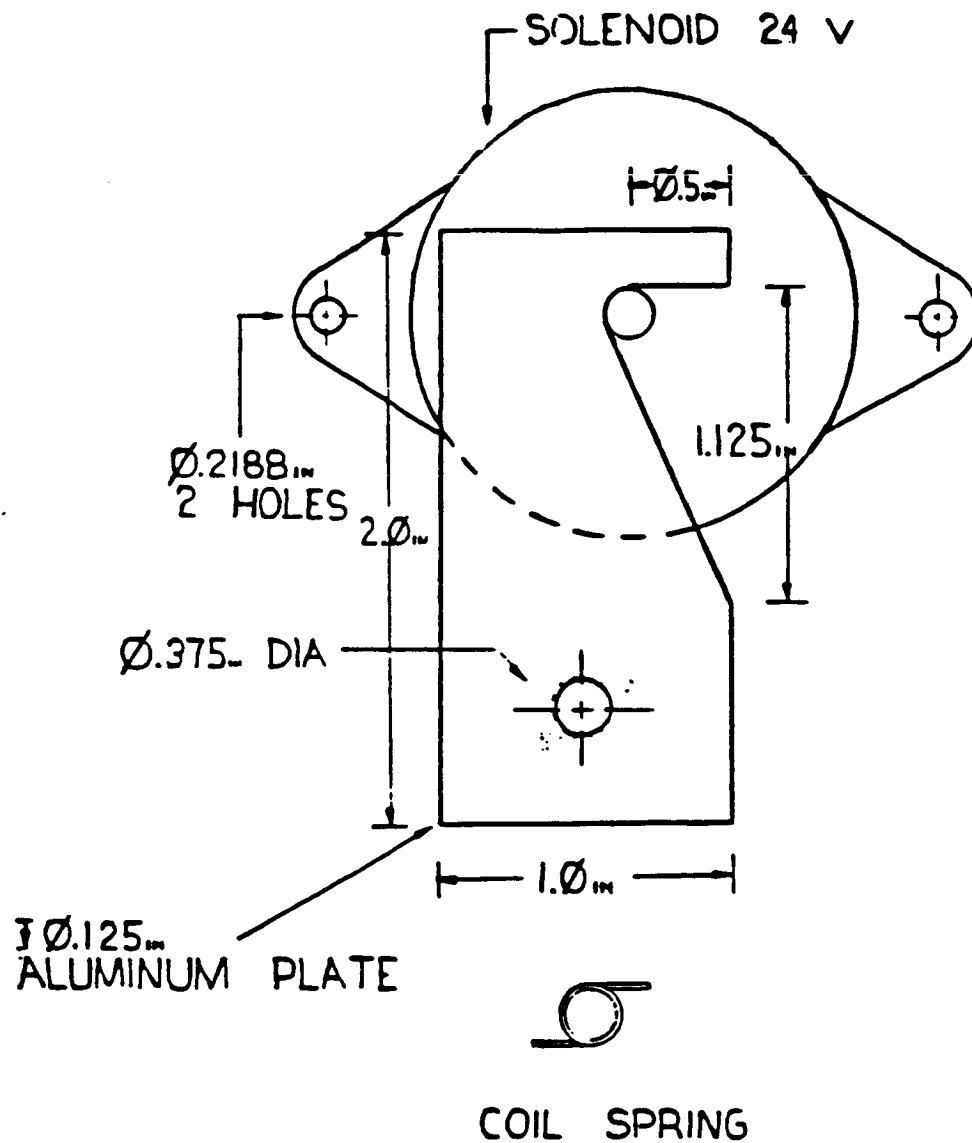


FIGURE 3.14



A modified version of the previous Hook/Lock device provides the restraint of the EEC to the TSSM. Located at each end of the Couch Support Platform is a double lock mechanism. These mechanisms are connected by a rigid bar. Each hook locks into a hook socket recessed in the bottom of the EEC. The hooks are released by pulling the handle of the connecting bar that is located outside the TSSM (Figure 3.15).

## **CHAPTER 20.0    OBSERVATIONS AND RECOMMENDATIONS**

Materials considered for the RES construction are; steel, aluminum and wood. Aluminum is chosen for the lift mechanism primarily because of its availability, workability and high strength-to-weight ratio [17]. Material selection for the extension mechanism was dictated by the availability of sliders. All of the sliders considered were made of steel.

A modified Hook/Lock Mechanism provides restraint of the EEC to the TSSM. The hooks used on this subsystem are mounted on the top of the Couch Support Platform. In the event of failure, these hooks cannot be released manually. This group recommends that the Couch Support Restraint Mechanism be redesigned with hooks placed in a more accessible location.

Difficulty in locating the appropriate compressed air piston-cylinders for the lift mechanism is a concern. If for any reason the proper cylinders cannot be located, a lift mechanism using an electric motor with a chain and sprocket could be used.

During transportation and testing of the RES components, breakage and damage may occur. Because spare parts and repair material might not be readily available at the testing facility, a repair kit consisting of repair materials and spare parts should be assembled to accompany the model to the test facility.

Throughout the design of RES, this group concentrated on designing devices that could be easily constructed with readily available components [18]. The best source for all components is Skycraft Surplus in Winter Park, Florida. Skycraft has a large selection of sliders, solenoids, air cylinders, and motors. A wide selection of available components allows design changes to be made during construction. Use of available components also reduces cost. A rough estimate of total cost is \$244.00 (Appendix B).

## COUCH RESTRAINT MECHANISM

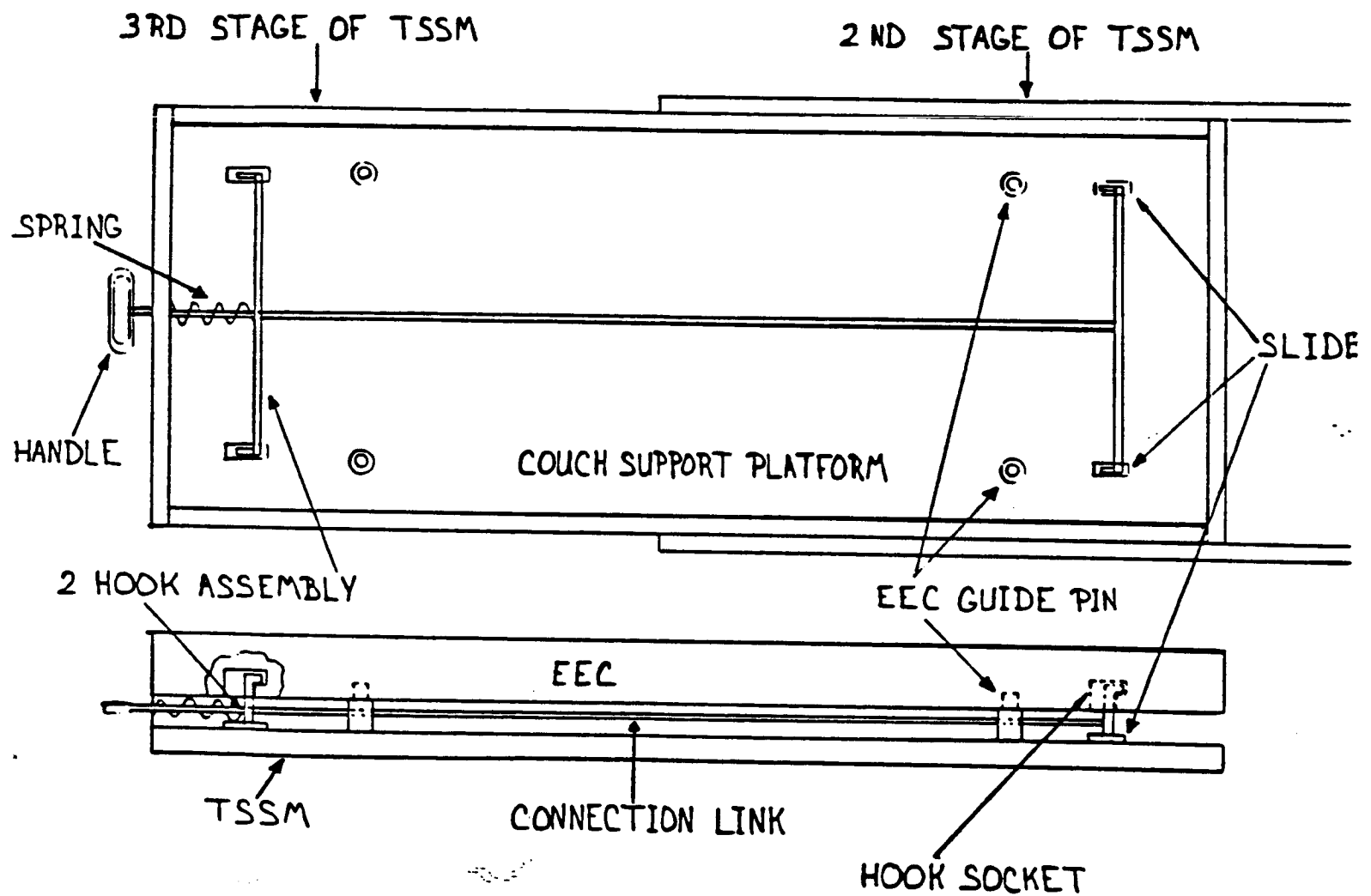


FIGURE 3.15

## **BUILDING PHASE - ACRV RAPID EGRESS SYSTEMS**

### **Chapter 21.0 LIFT MECHANISM CONSTRUCTION**

Refer to Figures 3.16 - 3.17 for a description of the work schedule and milestone chart for the lift mechanism construction.

### **Chapter 22.0 EXTENSION SUPPORT MECHANISM CONSTRUCTION**

Refer to Figures 3.18 - 3.19 for a description of the work schedule and milestone chart for the extension support mechanism construction.

### **Chapter 23.0 RESTRAINT MECHANISM CONSTRUCTION**

Refer to Figures 3.20 - 3.21 for a description of the work schedule and milestone chart for the restraint mechanism construction.

# FLIPEM CONSTRUCTION SCHEDULE

## A.1 Review Requirements

- A.1.1 Requirements [1/9-1/25]
- A.1.2 Drawings [1/9-1/25]
- A.1.3 Physical Characteristics [1/9-1/25]

## A.2 Drawings

- A.2.1 Sketches [1/11-1/25]
- A.2.2 Detailed Construction Drawings [2/1-2/15]

## A.3 Material Acquisition

- A.3.1 Pre-fabricated Components [1/25-2/2]
- A.3.2 Construction Materials/Fasteners [2/1-2/22]
- A.3.3 Construction Tools [1/25-2/22]

## A.4 Fabrication

- A.4.1 Modify Pre-fabricated Comp's [1/25-3/18]
- A.4.2 Fabricate Necessary Comp's [2/6-3/18]
- A.4.3 Component Integration [2/15-3/18]
- A.4.4 System Integration [2/22-3/18]
- A.4.5 Rework [3/1-3/18]

## A.5 Pretest

- A.5.1 Lifting Capacity [2/15-3/8]
- A.5.2 Lifting Speed [2/15-3/8]
- A.5.3 Redundancy [2/22-3/18]

## A.6 Finishing

- A.6.1 Paint [3/8-3/18]
- A.6.2 Decal [3/8-3/18]

FIGURE 3.16

# FLIPEM CONSTRUCTION MILESTONE CHART

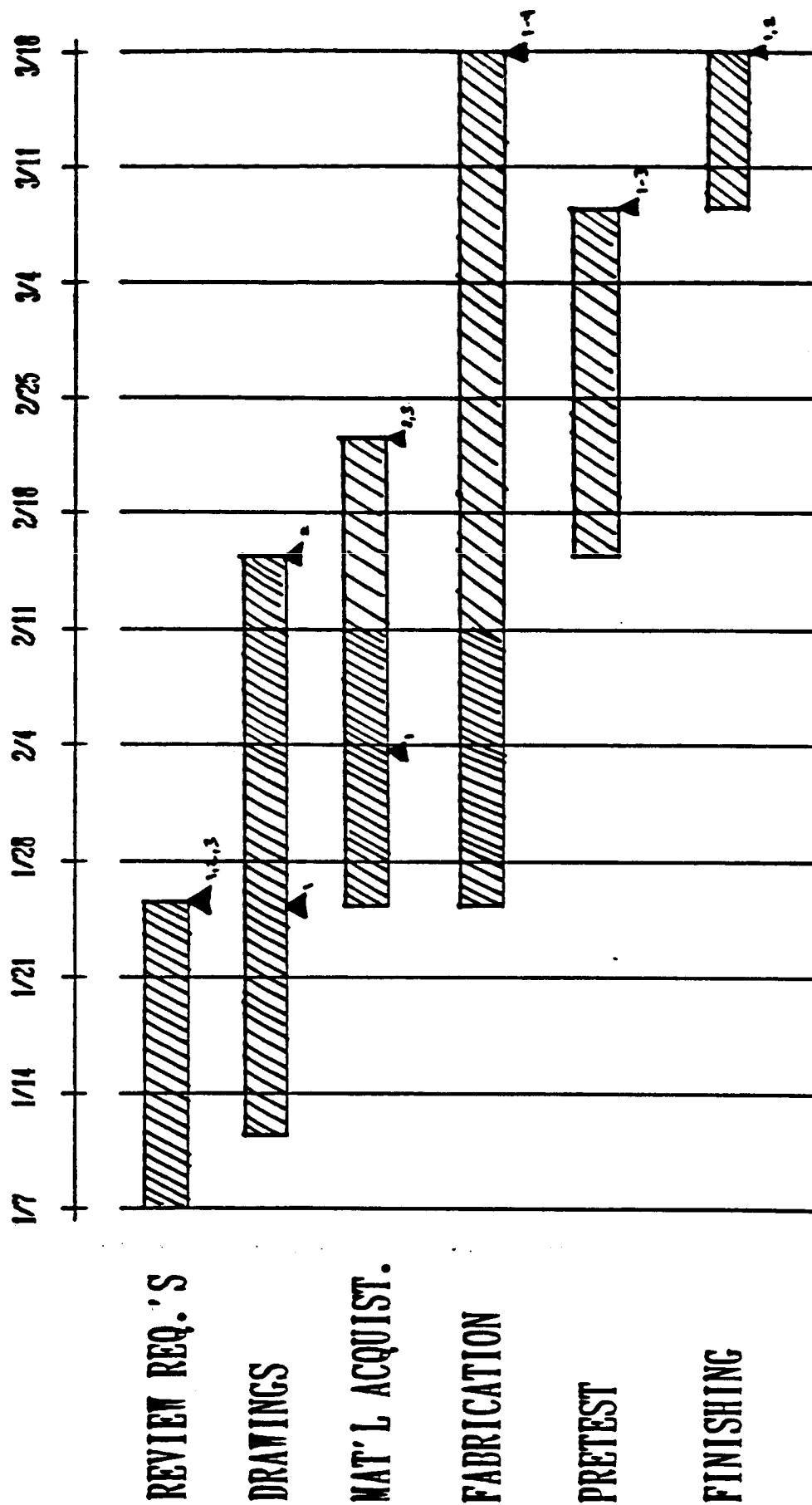


FIGURE 3.17

# THREE SLIDER SUPPORT MECHANISM CONSTRUCTION SCHEDULE

## B.1 Review Requirements

- B.1.1 Requirements [1/9-1/25]
- B.1.2 Drawings [1/9-1/25]
- B.1.3 Physical Characteristics [1/9-1/25]

## B.2 Drawings

- B.2.1 Sketches [1/11-1/25]
- B.2.2 Detailed Construction Drawings [2/1-2/15]

## B.3 Material Acquisition

- B.3.1 Pre-fabricated Components [1/25-2/22]
- B.3.2 Construction Materials/Fasteners [2/1-2/22]
- B.3.3 Construction Tools [1/25-2/22]

## B.4 Fabrication

- B.4.1 Modify Pre-fabricated Comp's [1/25-3/18]
- B.4.2 Fabricate Necessary Comp's [2/6-3/18]
- B.4.3 Component Integration [2/15-3/18]
- B.4.4 System Integration [3/1-3/18]
- B.4.5 Rework [3/1-3/18]

## B.5 Pretest

- B.5.1 Lifting Capacity [2/15-3/8]
- B.5.2 Lifting Speed [2/15-3/8]
- B.5.3 Redundancy [2/15-3/18]

## B.6 Finishing

- B.6.1 Paint [3/8-3/18]
- B.6.2 Decal [3/8-3/18]

FIGURE 3.18

# THREE SLIDER SUPPORT MECHANISM MILESTONE CHART

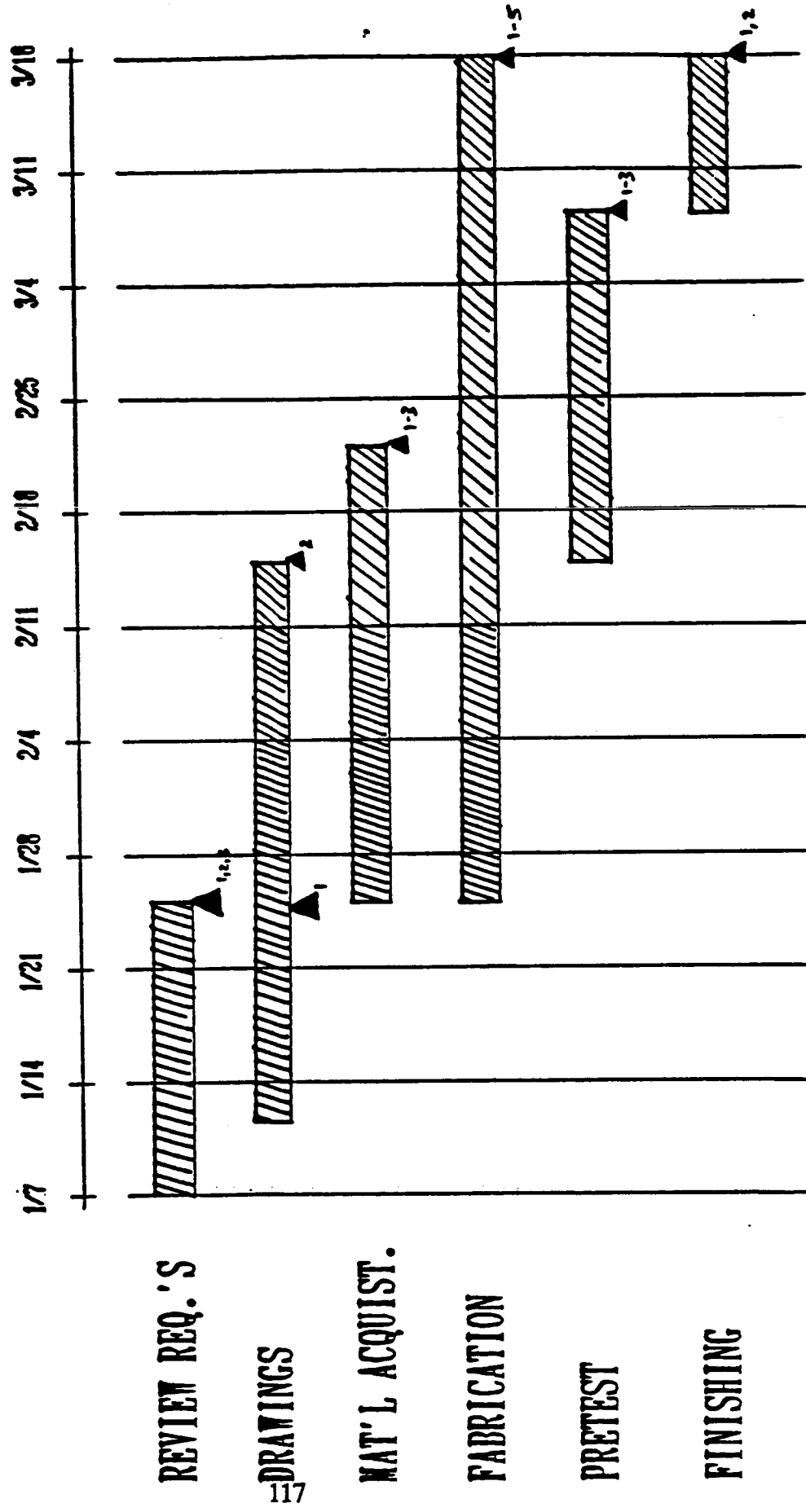


FIGURE 3.19

# RESTRAINT MECHANISM CONSTRUCTION SCHEDULE

## C.1 Review Requirements

- C.1.1 Requirements [1/9-1/25]
- C.1.2 Drawings [1/9-1/25]
- C.1.3 Physical Characteristics [1/9-1/25]

## C.2 Drawings

- C.2.1 Sketches [1/11-1/25]
- C.2.2 Detailed Construction Drawings [2/1-2/15]

## C.3 Material Acquisition

- C.3.1 Pre-fabricated Components [1/25-2/22]
- C.3.2 Construction Materials/Fasteners [2/1-2/22]
- C.3.3 Construction Tools [1/25-2/22]

## C.4 Fabrication

- C.4.1 Modify Pre-fabricated Comp's [1/25-3/18]
- C.4.2 Fabricate Necessary Comp's [2/6-3/18]
- C.4.3 Component Integration [2/15-3/18]
- C.4.4 System Integration [2/22-3/18]
- C.4.5 Rework [3/1-3/18]

## C.5 Pretest

- C.5.1 Lifting Capacity [2/15-3/8]
- C.5.2 Lifting Speed [2/15-3/8]
- C.5.3 Redundancy [2/15-3/18]

## C.6 Finishing

- C.6.1 Paint [3/8-3/18]
- C.6.2 Decal [3/8-3/18]

FIGURE 3.20



# RESTRAINT MECHANISM MILESTONE CHART

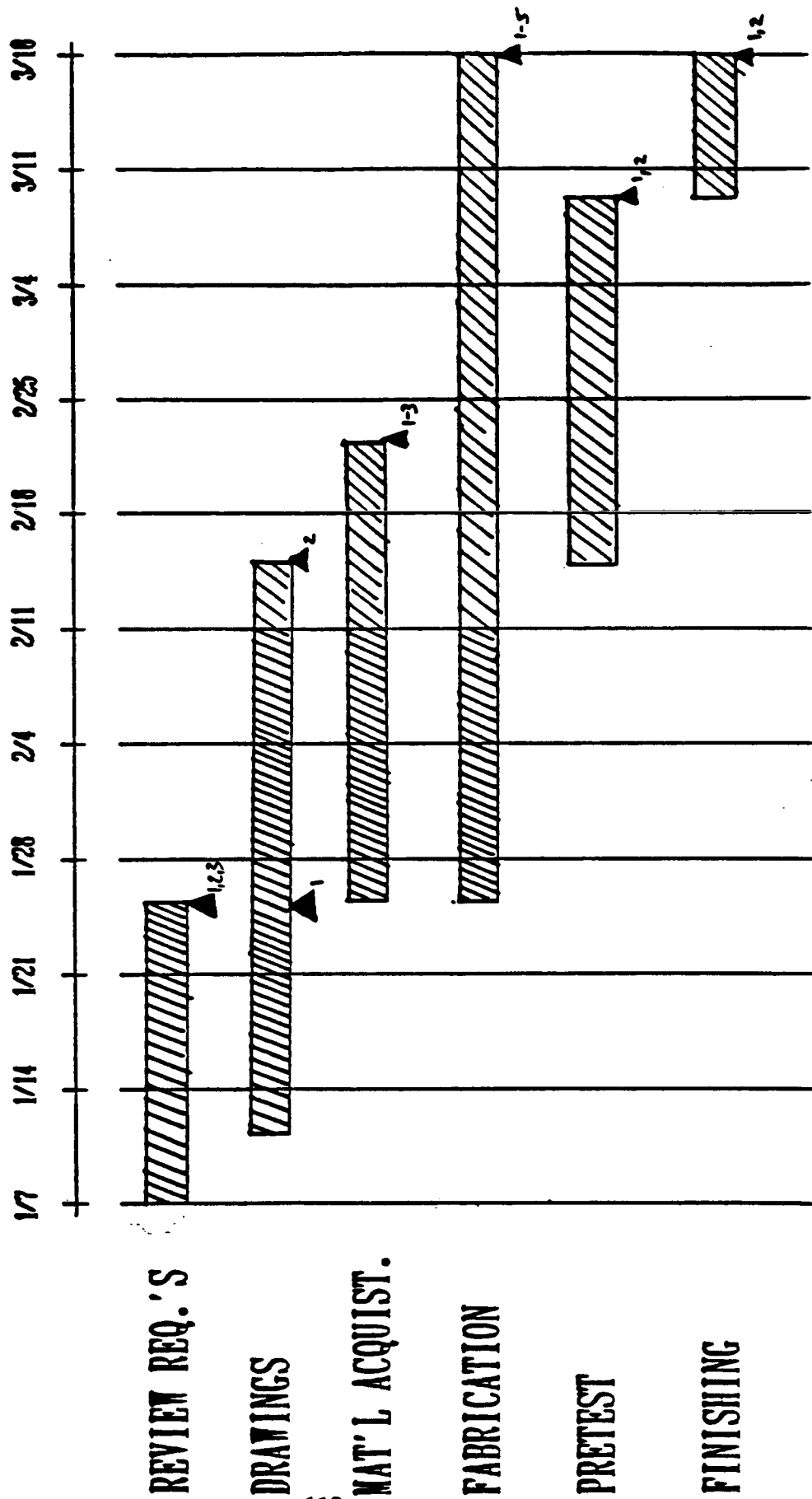


FIGURE 3.21

## **TESTING PHASE - ACRV RAPID EGRESS SYSTEMS**

### **Chapter 24.0 TEST PLAN**

This test plan details test objectives, procedures, and data collected that is applicable to the rapid egress system.

#### **- Test #1**

**Objective:** Ensure the adequate lifting capacity of the Four Link Injured Personnel Egress Mechanism (FLIPEM).

**Procedure:** 1.A: Lifting capacity measurement

- 1.A.1 Bolt egress mechanism to test bench.
- 1.A.2 Position FLIPEM in the locked retracted position.
- 1.A.3 Secure a weight equivalent to  $600/125 = 4.8$  lbs. to the couch.
- 1.A.4 Operate FLIPEM.
- 1.A.5 Video tape operation and record successful deployment.
- 1.A.6 Repeat procedures 1.A.4 and 1.A.5 with test bench at a +30 degree angle and again at a -30 degree angle.
- 1.A.7 Repeat procedures 1.A.2 - 1.A.6 with a weight of 3.6 lbs. and again with a weight of 6.0 lbs.
- 1.A.9 Repeat procedures 1.A.2 - 1.A.5 using alternate lift cylinder.

**Data Collected:** FLIPEM lifting capacity at varying angles, and redundancy of lift cylinders.

#### **- Test #2**

**Objective:** Measure rate of travel during egress operation.

**Procedure:** 2.A: Travel rate measurement

- 2.A.1 Repeat procedures 1.A.1 - 1.A.2
- 2.A.2 Activate the egress mechanism and measure the time required for complete deployment.
- 2.A.3 Video tape entire procedure.
- 2.A.4 Repeat procedures 2.A.2 - 2.A.3 five times.
- 2.A.5 Record times.

**Data Collected:** Egress system deployment time.

- Test #3

**Objective:** Verify FLIPEM's vertical and horizontal travel to ensure proper incorporation into ACRV model.

**Procedure:** 3.A: Vertical and horizontal travel measurements.

- 3.A.1 Repeat procedures 1.A.1 - 1.A.2.
- 3.A.2 Position vertically a 20x24 inch piece of cardboard adjacent to FLIPEM. Mark initial height and front edge location on cardboard.
- 3.A.3 Release FLIPEM.
- 3.A.4 Mark final height and front edge location on cardboard.
- 3.A.5 Repeat procedures 3.A.3 - 3.A.4, five times, using same initial position marks. Labeling each final position accordingly.
- 3.A.6 Measure horizontal travel and vertical travel and record

**Data Collected:** FLIPEM travel distances and tolerances.

- Test #4

**Objective:** Verify that the backward rotation of FLIPEM is prevented.

**Procedure:** 4.A: Backward rotation identification.

- 4.A.1 Repeat procedure 1.A.1.
- 4.A.2 Deploy FLIPEM.
- 4.A.3 Position cardboard from test #3, adjacent to FLIPEM and mark initial position.
- 4.A.4 Apply small amount of pressure by hand in the direction opposing FLIPEM motion.
- 4.A.5 Mark any rearward movement and record measurement.
- 4.A.6 Repeat procedures 4.A.4 - 4.A.5, five times.
- 4.A.7 Video tape first trial
- 4.A.8 Repeat five times procedure 4.A.4 - 4.A.5, disengaging one ratchet locking mechanism.
- 4.A.9 Videotape first trial.

**Data Collected:** Backward rotation caused by ratchet mechanism failure, and redundancy of the ratchet locking mechanism.

- Test #5

Objective: Verify the extension force of the Two Slider Support Mechanism (TSSM).

Procedure: 5.A: TSSM extension force measurement.

- 5.A.1 Repeat procedure 1.A.1.
- 5.A.2 Position FLIPEM in deployed configuration.
- 5.A.3 Secure a 4.8 lbs. weight to the couch.
- 5.A.4 Operate TSSM mechanism.
- 5.A.5 Videotape operation and record successful deployment.
- 5.A.6 Repeat procedures 5.A.4 and 5.A.5 with the test bench at a +30 degree angle and again at a -30 degree angle.
- 5.A.7 Repeat procedures 5.A.2 - 5.A.6 with a weight of 3.6 lbs. and again with a weight of 6.0 lbs.
- 5.A.8 Repeat procedures 5.A.2 - 5.A.5 with one motor disabled.

Data Collected: TSSM extension capacity, and redundant characteristics.

- Test #6

Objective: Verify proper horizontal travel of TSSM.

Procedure: 6.A: TSSM horizontal travel measurement.

- 6.A.1 Repeat procedure 1.A.1.
- 6.A.2 Place cardboard from procedure 3.A.2 adjacent to the TSSM.
- 6.A.3 Mark the initial position on the cardboard.
- 6.A.4 Deploy the TSSM.
- 6.A.5 Mark the final position.
- 6.A.6 Record the measurement.
- 6.A.7 Repeat procedures 6.A.2 - 6.A.6, five times.

Data Collected: TSSM extension distance.

- Test #7

Objective: Verify controlled unidirectional motion of TSSM upon deployment.

Procedure: 7.A: Backward motion identification.

- 7.A.1 Repeat procedures 1.A.1 - 1.A.2.

- 7.A.2 Deploy FLIPEM.
- 7.A.3 Deploy TSSM.
- 7.A.4 Apply small amount of pressure by, by hand, in the direction opposing TSSM motion.
- 7.A.5 Videotape to record any rear-ward movement.
- 7.A.6 Repeat procedures 7.A.3 - 7.A.5, five times.
- 7.A.7 Record observations.

Data Collected: TSSM rearward deflection distances.

- Test #8

Objective: Verify the proper operation of the FLIPEM restraint mechanism.

Procedure: 8.A: FLIPEM Restraint Mechanism operation.

- 8.A.1 Repeat procedures 1.A.1 - 1.A.2.
- 8.A.2 Simulate wave action and off nominal stress loading.
- 8.A.3 Visually inspect locking pins for failure and record any findings.
- 8.A.4 Release pins and record operation.
- 8.A.5 Repeat procedure 1.A.2
- 8.A.6 Remove one locking pin.
- 8.A.7 Repeat procedures 8.A.2 - 8.A.4

Data Collected: FLIPEM Restraint Mechanism integrity, operation and redundancy.

- Test #9

Objective: Verify proper operation of couch restraint mechanism.

Procedure: 9.A: Couch Restraint Mechanism operation.

- 9.A.1 Repeat procedures 8.A.1 - 8.A.7 for the Couch Restraint Mechanism.

Data Collected: Couch Restraint Mechanism integrity, operation and redundancy.

- Test #10

**Objective:** Verify proper operation of egress system using radio controlled release.

**Procedure:** 10.A: Radio control release validation.

10.A.1 Repeat procedure 1.A.1 - 1.A.2.

10.A.2 Connect radio control system.

10.A.3 Activate FLIPEM.

10.A.4 Activate TSSM.

10.A.5 Videotape entire procedure.

10.A.6 Record observations.

10.A.7 Repeat procedure 1.A.2.

**Data Collected:** Radio control operation of egress system.

- Test #11

**Objective:** Verify the water resistant capability of egress system without radio control devices.

**Procedure:** 11.A: Egress system submergence test.

11.A.1 Repeat procedures 1.A.1 - 1.A.2.

11.A.2 Without radio control devices attached, spray egress system with water (medium pressure) for 1 minute.

11.A.3 Manually deploy FLIPEM and TSSM.

11.A.4 Record observations.

**Data Collected:** Egress system's water resistance.

- Test #12

**Objective:** Verify complete and satisfactory operation of the egress system in pool.

**Procedure:** 12.A: Egress System operation in pool.

12.A.1 Position egress system on floor of ACRV model and secure.

- 12.A.2 Attach conical section (with hatch opening provided) to hemispherical base and seal.**
- 12.A.3 Attach attitude ring and mattress to model.**
- 12.A.4 Lower model into pool.**
- 12.A.5 Position video camera to view the hatch opening and mattress.**
- 12.A.6 Using radio control devices, activate FLIPEM and TSSM.**
- 12.A.8 Videotape entire procedure.**

## **Chapter 25.0      TEST RESULTS AND OBSERVATIONS**

This portion of the test report addresses the objective of each test performed, the procedures used, the data collected and observations and recommendations. All tests are recorded on videotape.

### **- Test #1**

- 1.A:** The purpose of Test #1 was to verify the adequate lift capacity of FLIPEM. FLIPEM was required to lift 75%, 100%, and 125% of the scaled weight of the egress couch (4.8 lbs), at angles of +30 degrees, 0 degrees, and -30 degrees. This was accomplished by following procedures 1.A.1 - 1.A.9 of the test plan.

Each of the requirements were completed successfully. FLIPEM had no trouble lifting the weights. In the case of the actual egress system to be used on orbit, a spring and damper should be studied as an alternate to the compressed gas cylinder.

### **- Test #2**

- 2.A:** Test #2 verified the rate of travel during egress operation. The extension rate had to be smooth so as not to propel the injured person from the couch. The scaled weights were used to simulate actual operation. This test was accomplished following procedures 2.A.1 - 2.A.5 of the test plan.

A stop watch was used to time the extension of the FLIPEM. The egress mechanism was actuated and extended fully. As mentioned above this process would be different in the actual ACRV if it is decided to use a different lifting mechanism.

### **- Test #3**

- 3.A:** FLIPEM travel was measured in this test. The mechanism was locked in the down position, then released. The rotation of the couch to its upright position was measured. A piece of foam was substituted for the cardboard in 3.A.2. This procedure was repeated five times, each time deploying to the same position.



in the same position each time showing that the rotation of the TSSM was correct.

**- Test #4**

- 4.A:** The backward rotation of the FLIPEM was verified in this procedure. Using the same piece of foam to mark position, a medium force was applied in the backwards position as per 4.A.1 - 4.A.9. The procedure was done first with the front ratchet disabled, then with the back ratchet disabled. The FLIPEM did not move when the force was applied. This test was performed five times with the same result.

The FLIPEM and ratchet system performed as designed. The ratchets prevented the backward movement of the FLIPEM. The ratchets could be fully removed and this test would still be satisfied. The stiffness of the gas cylinder prevents backward rotation independent of the ratchets.

**- Test #5**

- 5.A:** The force required to extend the couch with weight was verified in this test. Procedures 5.A.1 - 5.A.8 were followed giving satisfactory results. The different weights at the required angles were extended and retrieved with no problems.

The procedure was repeated five times. Each time the test was performed flawlessly. One motor was then disconnected from the TSSM. The entire procedure was then repeated with the required weights and angles, again the TSSM performed satisfactorily. This result proves the redundant characteristics of the mechanism.

**- Test #6**

- 6.A:** The extension distance of the TSSM is verified in this procedure. The procedures followed steps 6.A.1 - 6.A.7. A foam piece was substituted for the cardboard in step 6.A.2. The test was repeated five times to verify redundant characteristics.

The TSSM was fully extended for the procedure and the end of the TSSM was marked on the foam. Each extension was within one half inch of each other.

**- Test #7**

- 7.A:** Test 7.A was performed to verify controlled unidirectional motion of the TSSM upon deployment. Procedures 7.A.1 - 7.A.7 of the test plan were followed. With the TSSM deployed, a small amount of pressure was applied to the couch by hand in the direction opposing outward TSSM motion.

Test 7.A was repeated five times. All deflections measured were less than one-half inch. This deflection is less than 2.3 percent of the TSSM travel distance. To eliminate the backward deflection, extension cables with a greater stiffness must be used. Stiffer cables must however, be flexible enough to bend around the pulleys.

**- Test #8**

- 8.A:** Test 8.A was performed to verify proper operation of the FLIPEM Restraint Mechanism. Procedures 8.A.1 - 8.A.7 of the test plan were followed. The release pins were first loaded by subjecting the egress system to a simulated wave action. FLIPEM was then actuated, verifying the operation of the release pins. Redundancy was checked by removing one pin and actuating the FLIPEM.

The FLIPEM restraint system operated correctly with both pins in place. With either of the pins removed, the FLIPEM did not deploy. Redundancy of the Restraint Mechanism could be achieved by using more than two release pins. The forces on the remaining pins would be more evenly distributed allowing the FLIPEM to actuate.

**- Test #9**

- 9.A:** Test 9.A was performed to verify proper operation of the Couch Restraint Mechanism. Procedure 9.A.1 of the test plan was followed, which required repeating the steps used to test the FLIPEM Restraint Mechanism (Test #8).

The couch restraint system operated correctly with both pins in place. With only one pin in place, the couch was restrained from lifting off the support platform. However, because the lock pins are also the locating dowels, the couch was free to rotate about the single pin. Therefore, to

insure redundancy and stability in the couch restraint, additional non-locking, locating pins are recommended.

- Test #10

10.A: Test 10.A was a verification of the proper operation of the radio control release system. The radio control system was used to deploy the egress system throughout the testing program, and thus its operation was repeatedly verified.

For all tests conducted, the radio control operated correctly, releasing the FLIPEM Restraint Mechanism and extending the TSSM.

- Test #11

11.A: Test 11.A was a verification of the water resistant capability of the egress system. Procedures 11.A.1 - 11.A.4 of the test plan were followed. The RES was sprayed with water for one minute and then deployed. The radio control system was used instead of manual deployment as it is an integral part of the egress system.

The egress system operated correctly after being sprayed. The water resistant boxes which house the electronics worked well.

- Test # 12

12.A: Test 12.A was performed to verify the complete and satisfactory operation of the egress system in the pool. Procedures 12.A.1 - 12.A.8 of the test plan were followed. This test was done in a pool of still water.

The Rapid Egress System operated correctly while in the pool. However, because the water was still, this test served only to visually demonstrate the egress system incorporated into the ACRV.



## **SECTION IV.**

### **ACRV STABILIZATION CONTROL SYSTEMS**

#### **DESIGN PHASE**

- \* ATTITUDE RING
- \* DEPLOYABLE UNDERWATER PARACHUTE SYSTEM
- \* TEST EQUIPMENT

#### **BUILDING PHASE**

- \* ATTITUDE RING CONSTRUCTION
- \* ATTITUDE RING MATTRESS CONSTRUCTION
- \* PARACHUTE CONSTRUCTION
- \* STABILIZATION SYSTEM TESTBED CONSTRUCTION

#### **TESTING PHASE**

- \* TEST PLAN
- \* TEST REPORT



## **SECTION IV. ACRV STABILIZATION CONTROL SYSTEMS**

### **INTRODUCTION**

The objective of the ACRV Stabilization Control Systems effort is to determine the feasibility of stabilizing a one-fifth scale model of the Apollo Command Module on water using an underwater parachute system. The ACRV should be stabilized out of the frequency range which causes sea-sickness to prevent further injury or illness. This range is approximately 0.2 - 0.5 Hz. Associated with the underwater parachute system is the attitude ring which is the primary floatation device for the ACRV. The attitude ring may also aid in the stabilization of the ACRV.

Design concepts associated with the ACRV Stabilization Control Systems are presented in the design phase portion of this section. Work schedules and milestone charts are presented in the building phase portion and the test plan and results are detailed in the testing phase portion.

### **DESIGN PHASE - ACRV STABILIZATION CONTROL SYSTEMS**

#### **Chapter 26.0 ATTITUDE RING**

The attitude ring is a buoyancy control device which is attached to the ACRV to assist in floatation. The design requirements for the attitude ring model are as follows:

1. To accurately model the buoyancy characteristics of the actual ACRV attitude ring.
2. To accurately model redundancy characteristics.
3. To raise the ACRV to a position where the bottom of the hatch is at least 7.2 inches above the water line.
4. To prevent the ACRV from capsizing.

Refer to Appendix C for an analysis of the buoyancy characteristics of the ACRV model. The determining means process for selecting a design option which satisfies these requirements involves the consideration of four categories. These categories are: materials, physical structure, utility, and attachments. Following a description of these categories, five design options are presented. Finally, the advantages and disadvantages of each option are discussed.

## **26.1 Materials**

There is a wide range of materials which might be employed for the construction of an attitude ring. To narrow this range certain material characteristics must be defined. One characteristic is that the material used must be capable of accurately modeling the actual ACRV's attitude ring. For the model attitude ring to represent the actual attitude ring, its density characteristics should be similar. Another characteristic is the durability of the material. The material must withstand the stresses invoked during the motion of the model and the stresses induced by its attachment to the model. The material must also withstand lengthy and repeated exposure to water without damage. Other material characteristics to be considered for the model attitude ring should be evaluated for these characteristics.

## **26.2 Physical Structure**

The physical structure of the model attitude ring is a continuous ring or a multi-chambered ring. The continuous ring is a one piece component as shown in Figure 4.1(a). The multi-chambered ring may be composed of three or more separate ring sections each extending around a portion of the circumference of the ACRV model. Figure 4.1(b) shows an illustration of a three part, equally spaced ring. Each section extends 120 degrees around the circumference of the model. The ability to construct one or both of these structures must be considered when choosing an appropriate material for the ring.

## **26.3 Attachments**

Any proposed design option(s) must take into consideration the feasibility of attaching the ring to the ACRV model. Attachment methods for a rigid ring and a pliable ring must be considered. Some considerations for attachment concepts are availability of parts, complexity of attachment, weight of the attachment, mobility, cost and ease of construction. The attachments must be able to withstand the stresses induced by the motion of the model. They must not hinder or effect the buoyancy that the ring is simulating and must not interfere with the function of other components of the stabilization system. The selection of a design option(s) for the attitude ring must ensure that the means of attachment be consistent with the above mentioned characteristics.

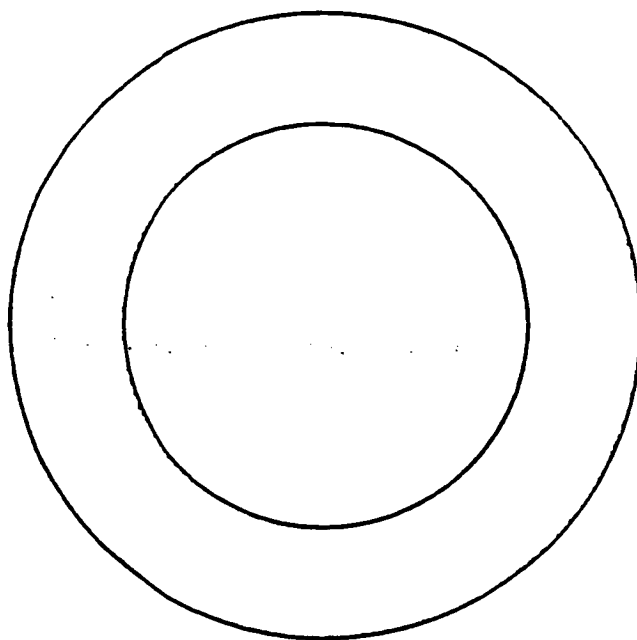
## **26.4 Design Options**

Several design options with their associated advantages and disadvantages are discussed in the remainder of this section. The options are based on material considerations, physical structure, and attachment possibilities. The five design options discussed are: 1) styrofoam ring, 2) inflatable rubber (inner tube) ring, 3) covered foam ring,



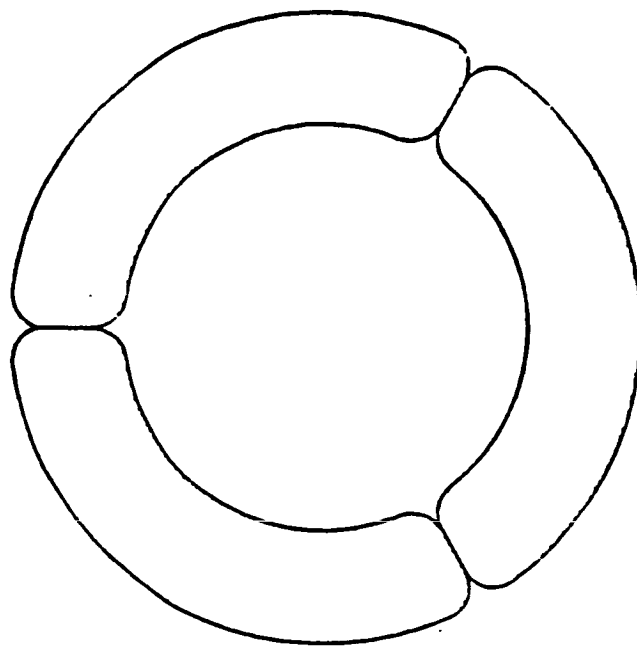
# ATTITUDE RING STRUCTURE

Continuous  
Ring



(A)

Multi-Chamber  
Ring



(B)

FIGURE 4.1

4) Balsa wood ring, 5) inflatable sphere ring (Tetherball or Volleyball). A basic illustration of each option is shown below.

Construction of a rigid styrofoam ring is the first design option. This type of ring has several advantages. The ring is simple to assemble in a continuous or multi-chambered arrangement. This type of ring does not leak. The use of a styrofoam ring simplifies the mathematical model of the stabilization subsystem since it is rigid. Styrofoam is a readily available material and is not expensive. Finally, this ring has the advantage of being simple to attach to the model. One possible attachment scheme (Figure 4.2) consists of a long bolt and flat washer assembly passing directly through the body of the ring. A piece of wire or cord is attached at the end of the bolt assembly and connected to a threaded eyelet on the base of the model.

There are disadvantages to using a styrofoam attitude ring. Styrofoam has a tendency to weaken after long exposure to water which often results in its decomposition. The material is also brittle and may be susceptible to fracture under stress. The material may also be too stiff to model actual ring flexibility.

A rubber tube, which is similar to an inner tube, is the second design option. An illustration of this type of ring with a proposed method of attachment is shown in Figure 4.3. The attachment consists of wrapping a wire or cord securely around a canvas-covered rubber tube and attaching it to the model by passing it through a threaded eyelet. This type of design has an advantage of being simple to fabricate for a continuous ring structure. It is able to attain the buoyancy required to support the model, and to simulate the flexibility of the actual ACRV attitude ring.

There are disadvantages with this type of attitude ring. First, the ring is susceptible to leaks. The resistance to puncture could be minimized by the use of a canvas covering, but the possibility of leakage would still exist. This particular type of material would be difficult to fabricate into a multi-chambered ring. Finally, the attachment of the ring to the model may prove to be complex.

The third design option is to use covered foam rubber for the construction of the ring. This material is similar to that used for a water-ski vest. An illustration of this option with a proposed attachment is shown in Figure 4.4. One advantage of using covered foam rubber is that it does not leak. Another, is the fact that it is readily available. A continuous or multi-chambered ring could be fabricated with the use of a mold. This type of ring could be attached to the model without difficulty.

A disadvantage in using covered foam rubber is the fabrication of the ring requires the use of a mold. This material may be more expensive than the other materials that are being considered.

# STYROFOAM RING ATTACHMENT

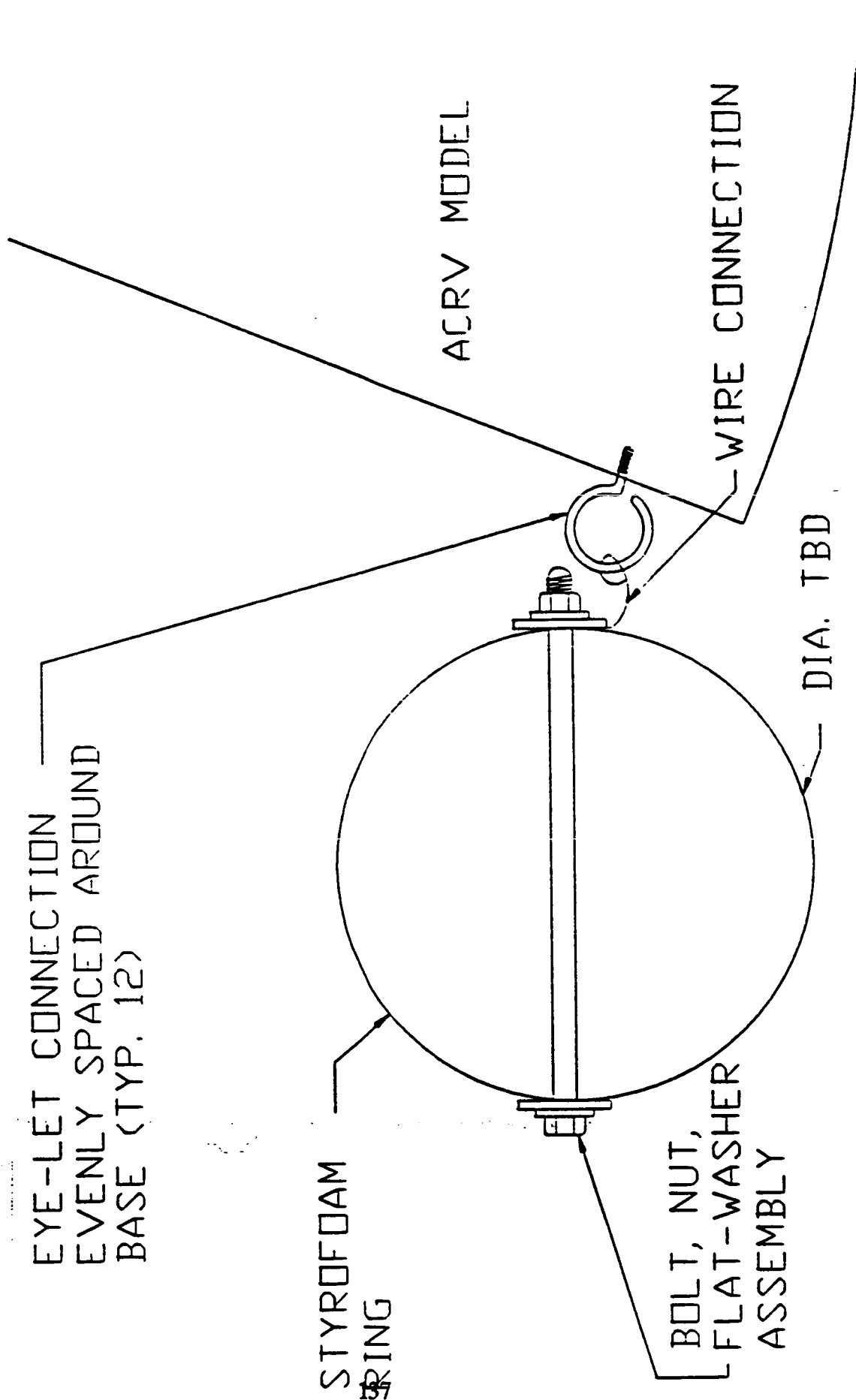


FIGURE 4.2

## INNER TUBE OPTION

EYE-LET CONNECTION  
EVENLY SPACED AROUND  
BASE (TYP. 12)

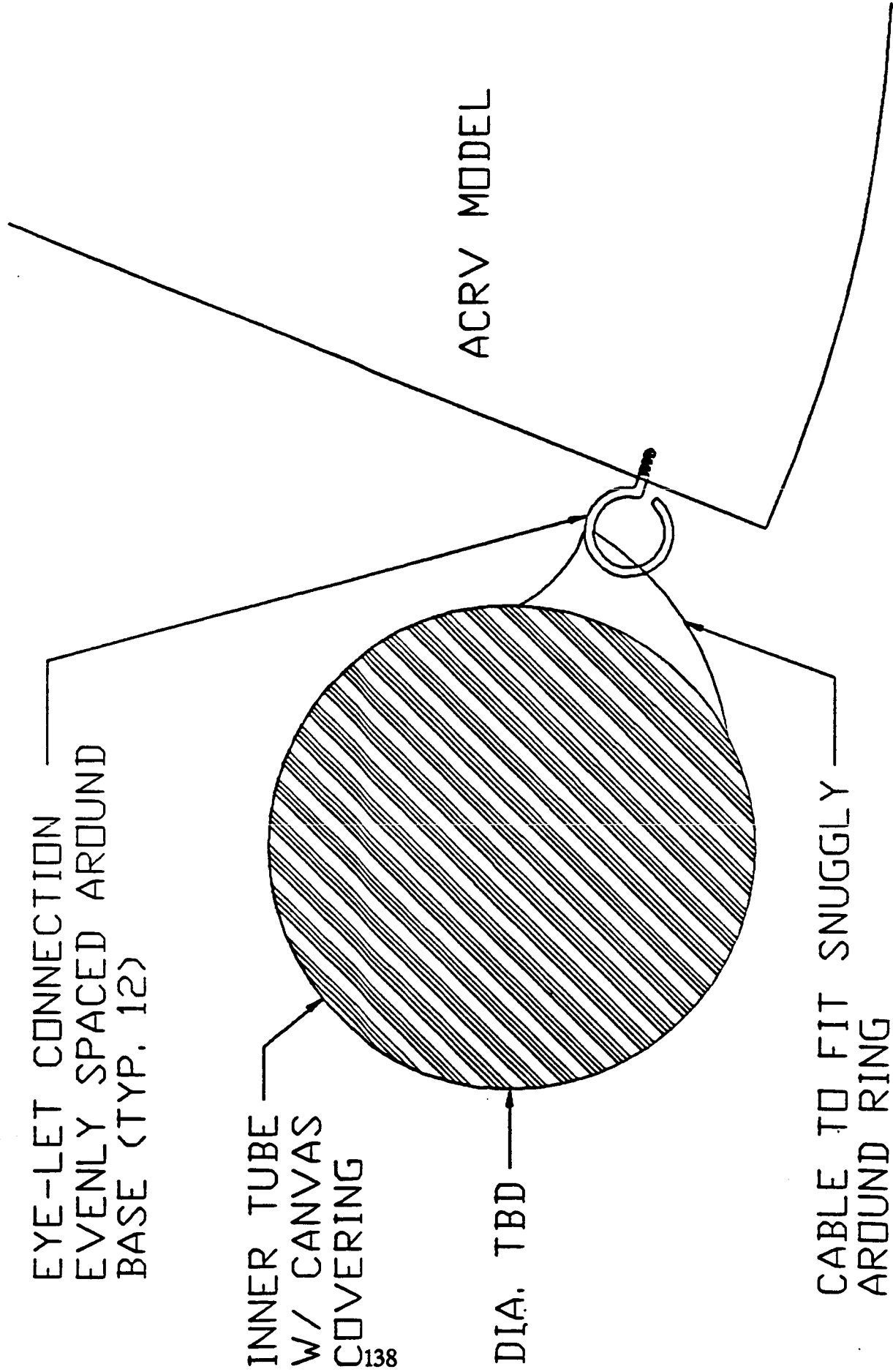
INNER TUBE  
W/ CANVAS  
COVERING  
138

DIA. TBD

ACRV MODEL

CABLE TO FIT SNUGLY  
AROUND RING

FIGURE 4.3



# COVERED FOAM RUBBER OPTION

EYE-LET CONNECTION  
EVENLY SPACED AROUND  
BASE (TYP. 12)

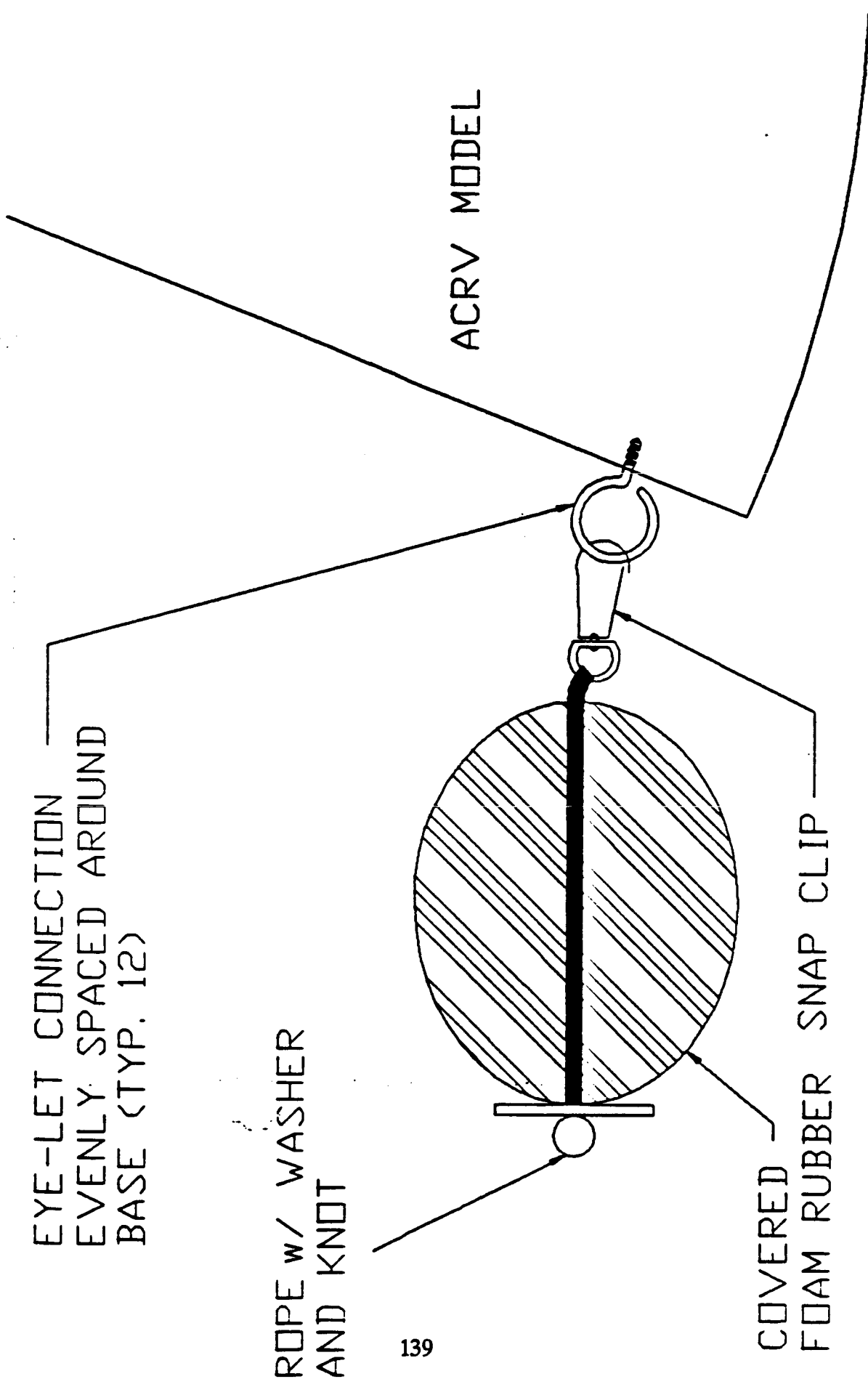
ROPE w/ WASHER  
AND KNOT

139

ACRV MODEL

COVERED  
FOAM RUBBER SNAP CLIP

FIGURE 4.4



The fourth design option involves using balsa wood to construct the attitude ring. An illustration of this option is shown in Figure 4.5. Advantages of using balsa wood are that balsa wood does not leak and is readily available at low cost. Since it is rigid, mathematical modeling is simplified. A balsa wood attitude ring is easy to attach to the model. One method of attachment is shown in Figure 4.5.

There are disadvantages when using balsa wood for the ring. First, it is more difficult to fabricate due to the length of time and precision involved in shaping the torus shape. Exposure to water for long periods of time decreases its durability. Also, the flexibility of the actual ACRV attitude ring could not be demonstrated with balsa wood.

The fifth design option is to use inflatable spheres to form a multi-chambered ring. This concept is shown in Figure 4.6. The spheres used are similar to tether balls which have a ring attached to their outer surface. This concept is also illustrated in Figure 4.6. Advantages of using spheres are similar to those for the inner tube, however, the probability of leakage is reduced. There is little, if any, fabrication involved when using this concept. Another advantage is the availability of tether balls. Since the tether balls are air filled, they provide a better model for the ACRV attitude ring.

The disadvantages of tether balls must be considered. Use of a volleyball, as shown in Figure 4.6, complicates attachment. The redundant buoyancy provided by multiple balls is unnecessary and could adversely affect the buoyancy characteristics. Finally, the use of inflatable spheres does not resemble the appearance of the proposed ACRV attitude ring.

## **Chapter 27.0      DEPLOYABLE UNDERWATER PARACHUTE SYSTEM (DUPS)**

The Deployable Underwater Parachute System is a system which is deployed after landing to assist in stabilization. The design requirements for the DUPS model are:

1.     The system must encompass a full range of possible configurations.
2.     The system components must be interchangeable.
3.     The system must be able to withstand the test conditions.

This section has four separate categories: material considerations, construction considerations, utility considerations and design options. A description of these categories and their influence on the design options is presented first. This is followed by descriptions of design options for the attachments, parachutes, and cables. Each design option is accompanied by a list of its advantages and disadvantages.

## BALSA WOOD OPTION

EYE-LET CONNECTION  
EVENLY SPACED AROUND  
BASE (TYP. 12)

BALSA WOOD  
RING

ACRV MODEL

WIRE CONNECTION

DIA. TBD

BOLT, NUT,  
FLAT-WASHER  
ASSEMBLY

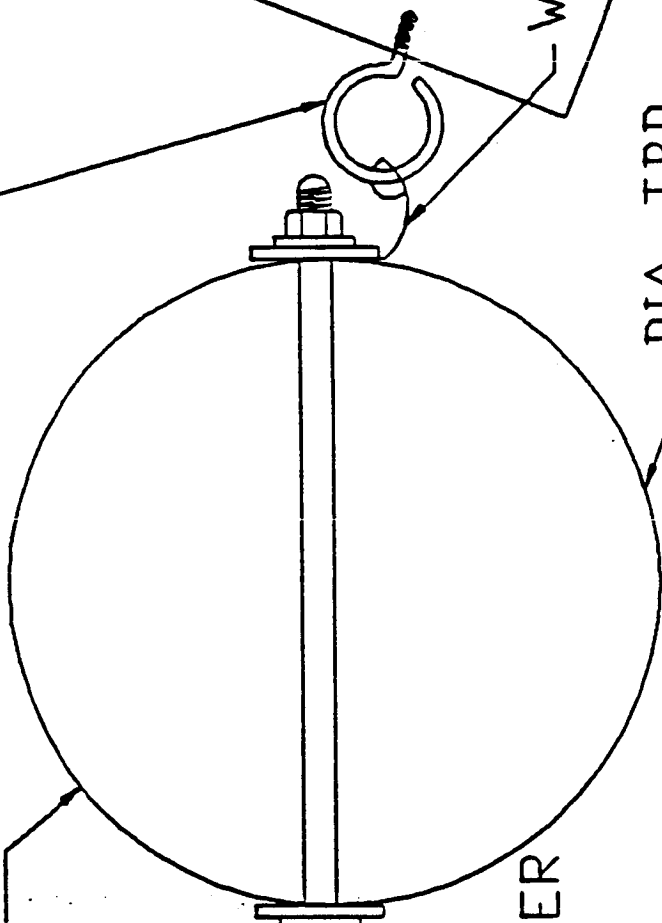
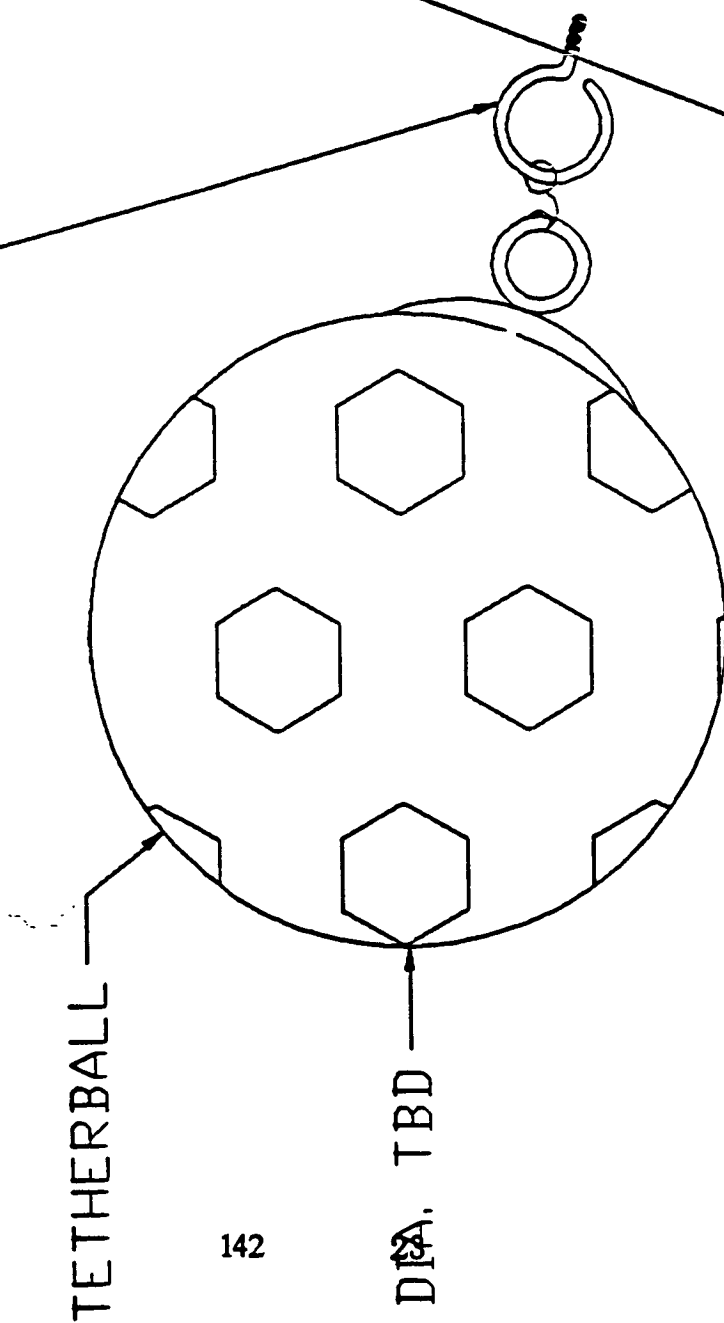


FIGURE 4.5

# TETHER BALL OPTION

EYE-LET CONNECTION  
EVENLY SPACED AROUND  
BASE (TYP. 12)



ACRV MODEL

FIGURE 4.6



## 27.1 Materials

There are two areas where materials need to be considered: cables and parachutes. The materials used for the cables must provide a wide range of elasticity (spring constants) from stiff to elastic. Since the relationship between the elasticity of the cable and the damping has not been established, the ability to attach cables with different spring constants to different parachutes must be allowed. This procedure will allow the correct amount of damping and elasticity needed to prevent seasickness. The cables are also required to accept the loads and stresses placed upon them without failure. Therefore, the cables must operate in their elastic region and not be subject to plastic deformation. Plastic deformation of the cables prevents them from returning to their original shape and shortens their life. The cables must not deteriorate in the test environment. Because the test environment is water, the cables must not rust or cause adverse affects to other systems. Since the test environment is a fluid, the cables will move about freely and may become entangled. Therefore, cable material that performs in a predictable manner must be chosen.

Two types of parachute material are considered; porous and non-porous. The porosity of the material affects the design and complexity of the parachutes. Porosity also affects drag, opening forces, filling time and the critical opening velocity [19]. Filling time is the time it takes to fully open the parachute and is affected by the porosity and size of the canopy. The filling time decreases with a less porous parachute and increases with a highly porous one. Increasing the filling time of the parachute increases its response time and thus decreases the damping response of the parachute. However, a rapid filling parachute causes higher deceleration and forces on the system.

The parachute will be cyclicly loaded and unloaded throughout the tests. Therefore, the material will be subject to cyclic stresses which cause fatigue, decreasing the material life [20]. The material must also be able to withstand exposure to water for extended periods without damage. Since material failure during an experiment invalidates the results, the material must not tear or break during the test.

Once the parachutes deploy, they must submerge, therefore a point mass is needed. The point mass keeps tension in the cables on the downstroke. If the cables are not kept taut on the downstroke, the drag force on the parachutes causes them to fall more slowly than the ACRV model. This drag results in slack in the cables and a non-functioning stabilization system. The type of material used for the weights must be heavy to have a good negative buoyancy, while having a predictable drag coefficient.

Other material properties that must be considered are cost, availability, and workability. Each of these properties must be evaluated for any material chosen for the cables, parachutes, and point masses.

## 27.2 Construction

The arrangement of the parachutes directly affects the construction of the system. As previously mentioned, one of the design requirements is to have interchangeability of components. This requirement includes the ability to try various parachute arrangements such as two or more parachutes in series as shown in Figure 4.7. The parachutes must also attach to various locations around the ACRV model (Figure 4.8). The construction of the model, parachutes, cables and attachments must allow for these arrangements. Also, the parachute construction is critical to its performance.

## 27.3 Utility

There are two primary utility considerations to be made. The first is the changing of parachute arrangements. The possible short testing time necessitates the ability to quickly change the parachute arrangements. Each component must also be easily accessible to quickly perform a change or repair during testing. The second utility consideration is the size of the testing facility used. Facility size directly affects possible designs. This factor dictates the size of the largest possible parachute that can be tested, as well as, the total length of the cable and parachute arrangements.

## 27.4 Design Options

### 27.4.1 Attachments

The method used to attach the various components together must be universal for all components. An immediate and easy form of attachment between the components is to tie the loose end of one component to the other. While this configuration may seem to be the least expensive and easiest method, it is the least practical. DUPS may employ dissimilar materials that may not "tie" together. For instance, tying a rubber bungee cord to a steel cable may result in a connection that may not stay together under zero stress. For this reason, most of the design options for the attachments section are modular identical design connections which join two rings. This assumes that the connecting lines (bungee cords, etc.) are available with or attachable to rings.

There are five ring-to-ring connectors examined here: rope tied, wire-twist tied, cable-tie connected, fishing line-joiner connected, and ring-carabinier connected. The rope tied connection is simple. A short piece of rope is looped through the two rings and tied in a knot. This arrangement is similar to the wire-twist tie where the rope is replaced by a wire and its ends twisted together. The cable-tie connection is also similar. These three connectors are expendable and easy to attach. However, they also present the disadvantage of being difficult to detach. Rope knots are hard to undo when wet, wire twists can come loose if not double wrapped, and cable ties can only be cut. These detachment difficulties

## PARACHUTES IN SERIES

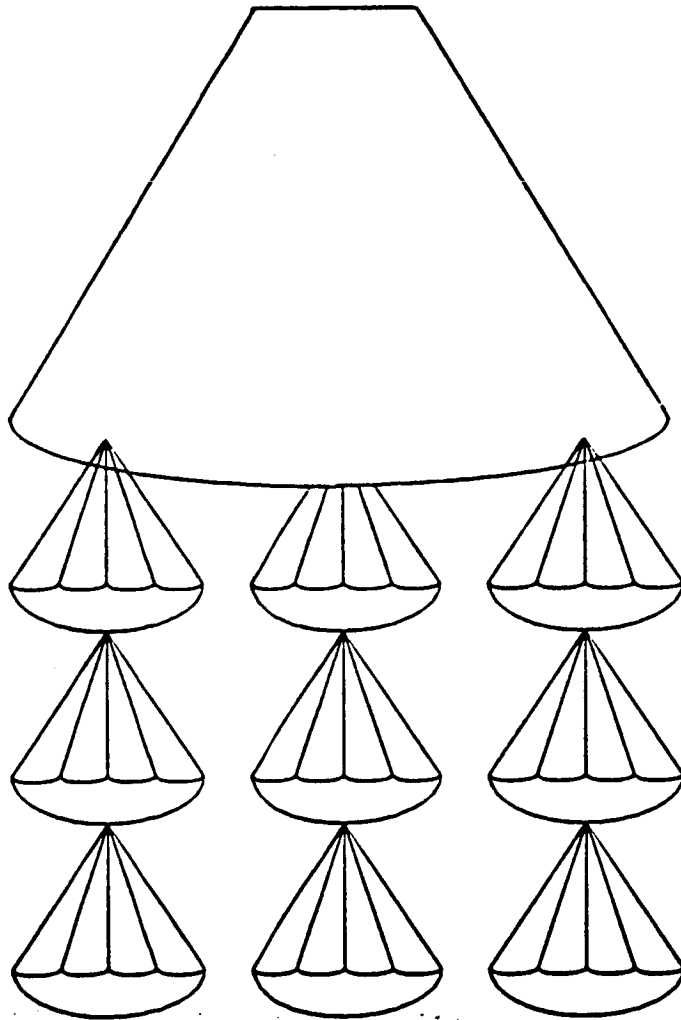
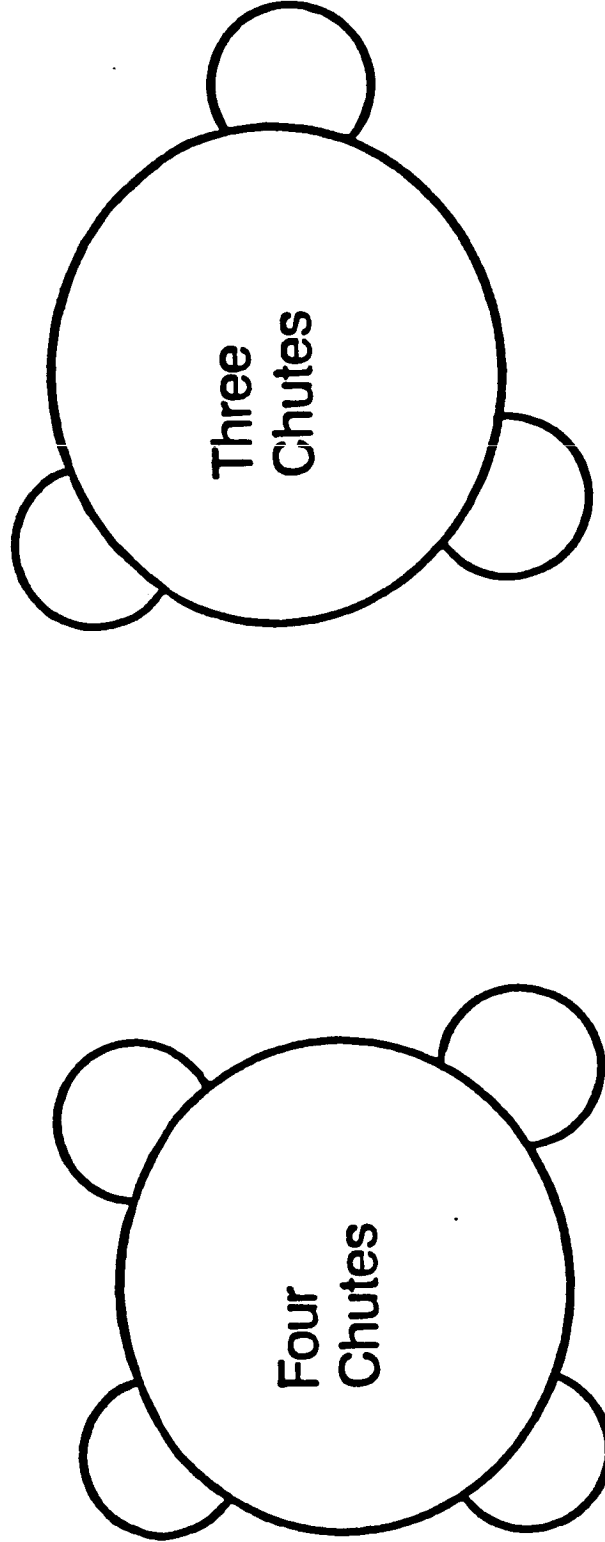


FIGURE 4.7

**PARACHUTES ATTACHED AT  
VARIOUS LOCATIONS**



**FIGURE 4.8**

give rise to the last two of the connection options: the fishing line-connector and the ring-carabinier. Both of these options operate similar to safety pins in that they open and close with a switch-like motion. The disadvantage in using either is the cost.

#### 27.4.2 Parachutes

The wave motion for testing will be modelled as a steady-state sinusoid. The purpose of the Deployable Underwater Parachute System (DUPS) is to dampen the model's vibrational response to this motion. This reduction may be accomplished when the parachute is open as the model goes up the wave, the upstroke, and closed as the model goes down the wave, the downstroke (Figure 4.9). The parachutes must close on the downstroke to keep the cables taut. This insures that the damping effects occur on the upstroke. The damping effects of the parachute system depend on drag force, opening force, and critical opening velocity of the parachutes.

The drag force of the DUPS depends on the porosity, shape, size, velocity, vent size, and line length. The shape refers to the canopy and is seen from a side view of a parachute. The geometry is the shape seen from a top or bottom view. The velocity is related to the drag coefficient which is proportional to the area. Vents are openings in the canopy surface which are less than 1% of the total canopy area. These vents affect the filling time, drag coefficient, and critical opening velocity. Line length refers to the length of the cables attached directly to the canopy [19].

The opening force is the decelerating force exerted on the parachute. This opening force occurs after the snatch force, or the force caused by the initial deployment of the parachute. The opening force is also influenced by the canopy drag as it slows the parachute to its terminal velocity.

The critical opening velocity is the slowest speed at which the canopy does not fully develop. Speeds above this cause the canopy to squid. Squidding is when the canopy does not fully develop and is usually 25% to 33% its normal shape and decreases the damping effect of the DUPS.

Each design option for DUPS must consider the above factors. The design options for DUPS are: 1) fabric parachutes, 2) Rocker Stoppers, 3) semi-rigid umbrella parachutes, and 4) interlocking curved plates. Advantages and disadvantages of each design option are given.

The primary advantage of a fabric parachute is how well the design conforms to the actual ACRV. Fabric can be packed into a small volume, and will be easy to deploy. However, these advantages are not the same for the model.

## DUPS OPENING AND CLOSING CYCLES

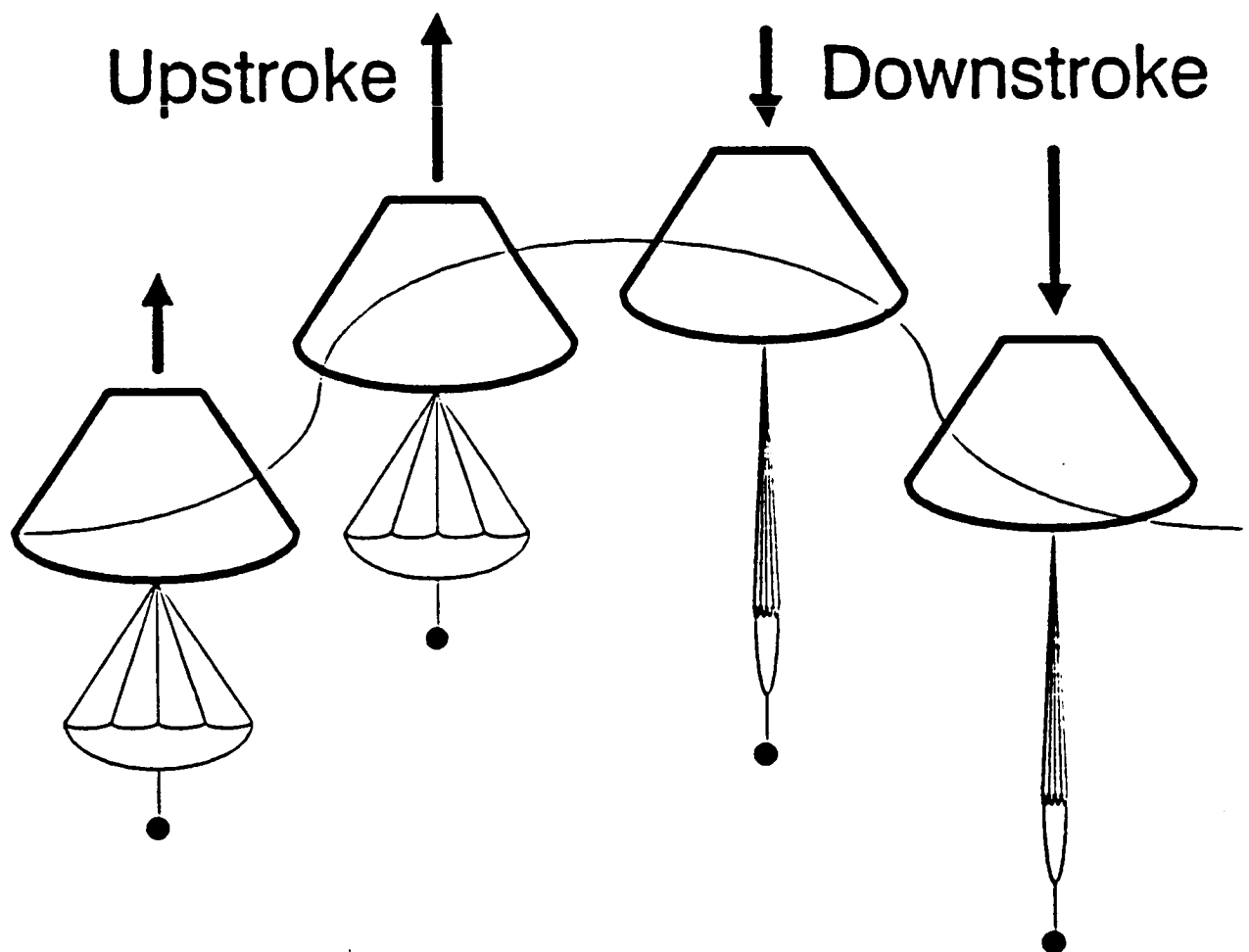


FIGURE 4.9

The model will be used to determine if DUPS is a feasible solution to dampen wave motion. The feasibility of fabric parachutes requires further study. A disadvantage of fabric parachutes is complexity. A 30 foot parachute in air and a 10 foot parachute in water act similarly. This is illustrated by a comparison of Reynolds numbers for each [21]. For a parachute to work correctly in air, the amount of weight, volume, drag force, glide angle, inflation time, and critical opening velocity must be known. These factors are constant for a 30 foot parachute in air. However, for a 10 foot parachute in water, with harmonic wave motion; the drag force, inflation time, and critical opening velocity vary. Moreover, the inflation time may be too high for the parachute to work efficiently. The canopy may not open on the upstroke.

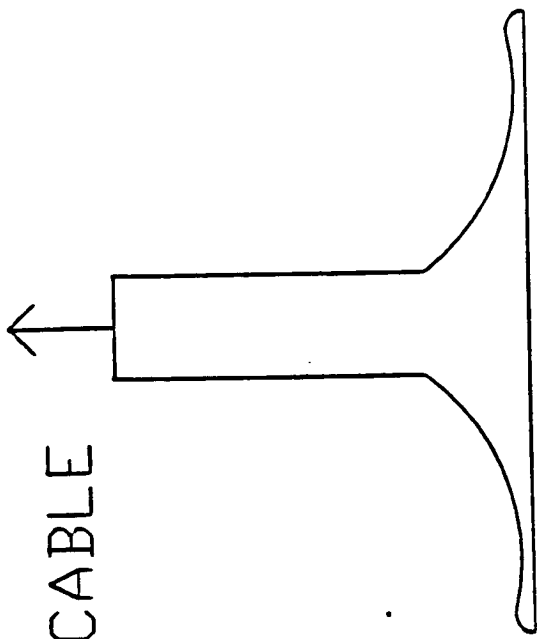
The above factors illustrate the complexity in the design of a fabric parachute for water. This complexity is another disadvantage. A fabric parachute must be constructed exactly to design specifications. Therefore, the parachute must be fabricated by a parachute manufacturer which adds cost and time to fabrication. Another disadvantage is with the fabric. Although the parachute should be nonporous and made of a strong material, the cost of such material is high. The parachutes on the model will be made of the least expensive material that will withstand testing.

An alternative to fabric parachutes is a product known as Rocker Stoppers (Figure 4.10). Rocker Stoppers are round plates with curves carved on the top to vent the water. One advantage to Rocker Stoppers is they come pre-fabricated and can be ordered by mail. Another advantage is cost. Rocker Stoppers sell for \$6 each. Finally, Rocker Stoppers are heavier than material parachutes and may not require a point mass to sink them.

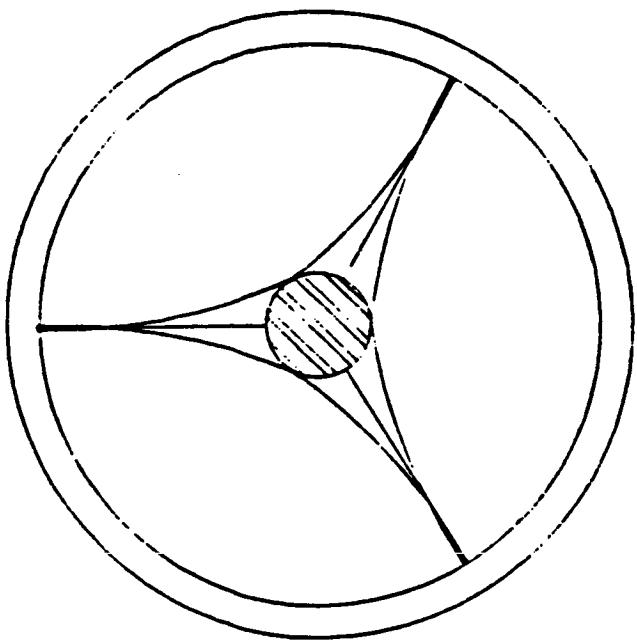
Although Rocker Stoppers have an advantage of being pre-fabricated, this is also a disadvantage. Besides determining the feasibility of DUPS, the tests must establish an optimal arrangement and size of the DUPS. Therefore, the tests must consider different radii for the parachutes. The Rocker Stoppers come in only one size. Another disadvantage of Rocker Stoppers is their structure. Since Rocker Stoppers are rigid, they do not collapse on the downstroke. Compared to other design options, Rocker Stoppers have a higher coefficient of drag on the downstroke. The most important disadvantage to Rocker Stoppers is consideration of the actual ACRV. Rocker Stoppers are not compact and easy to deploy from an Apollo Command Module. Although Rocker Stoppers may work well on the model, this concept may not work well on a real ACRV.

Another design option for DUPS is an umbrella parachute (Figure 4.11). Fabric is woven around a metal frame with strings at the joints. The springs help to open and close the parachute, which is an advantage over the fabric parachute. The springs decrease the inflation time and the parachute opens quickly on the downstroke and closes on the upstroke. However, the addition of the flexible frame to the fabric creates disadvantages. As with a fabric parachute, the umbrella parachute is hard to fabricate and the material may tear. Unlike the fabric parachute, the umbrella parachute could corrode if the frame and spring are made of metal. Finally, a key disadvantage of the umbrella parachute is the same

ROCKER STOPPER OPTION



SIDE VIEW



TOP VIEW

FIGURE 4.10



# UMBRELLA PARACHUTE OPTION

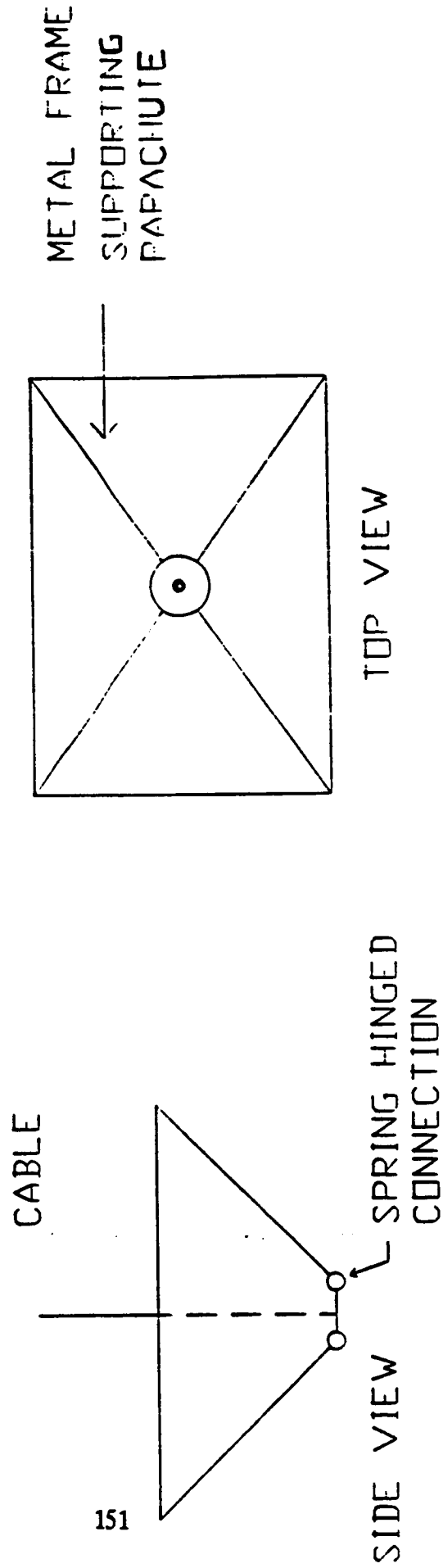


FIGURE 4.11

for the Rocker Stoppers. The umbrella design may not be utilized on the actual ACRV due to lack of space or difficulty in deployment.

The final design option is hinged curved plates (Figure 4.12). A thin central plate is fixed at both ends to cables that hold it in place. Other plates are stacked above and below the central plate. These plates are connected to each other at one side. Cables are attached to the free sides of the top and bottom plates. On the upstroke the plates open creating a hemispherical parachute. On the downstroke the plates close, stack above and below the central plate.

The self-folding action is the main advantage of the curved plates. Another advantage of this design is the cost of the components. This design requires a sheet of metal and a thin cable to connect the plates. No point mass is needed to sink this parachute design on the down stroke. Although the curved plates are inexpensive, their overall construction is difficult. The plates must have a specific curvature and be flexible enough to operate when connected. These details will take careful design and exact workmanship. The last disadvantage of this design is the same as the Rocker Stoppers and the umbrella parachutes. The actual ACRV is limited by the amount of space in the craft, the weight it can carry, and the means by which the DUPS can be deployed. The curved plates may not conform well to these limitations. However, the plates may conform better than the Rocker Stoppers and umbrella parachutes.

### 27.4.3 Cables

The design options for the cables are discussed in this section. For each design option, advantages and disadvantages are given. The design options allow for a range of elasticity in the cables. The design options include: stiff – 1) steel, 2) graphite, and 3) heavy monofilament; or elastic – 1) rubber (bungee cord), 2) springs, 3) light monofilament.

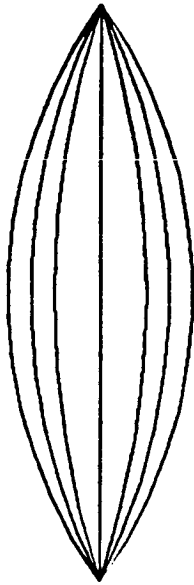
The first design option for a stiff cable is steel. Steel has several advantages, it is readily available, inexpensive, and has a high spring constant. Since steel is readily available, acquiring parts to construct attachments will not be difficult or expensive. Its disadvantages are that it may corrode in the water and could be hazardous if it frays.

The second design option is a graphite cable. Graphite has the advantage of a high spring constant and it does not corrode in water. The disadvantages of graphite are expense and workability. Graphite is costly and not as ductile as steel.

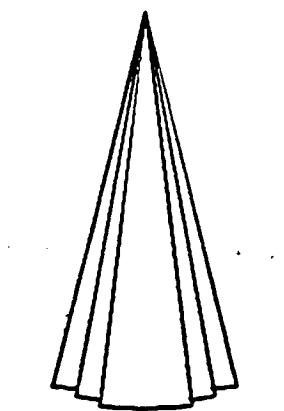
The final design option for a stiff cable is heavy monofilament. An example of this is a heavy fishing line. The monofilament has the advantages of being inexpensive and easy to work with. Heavy monofilament has a lower spring constant than steel or graphite and thus may be an acceptable choice for an intermediate elastic material.

## HINGED PLATES OPTION

Closed

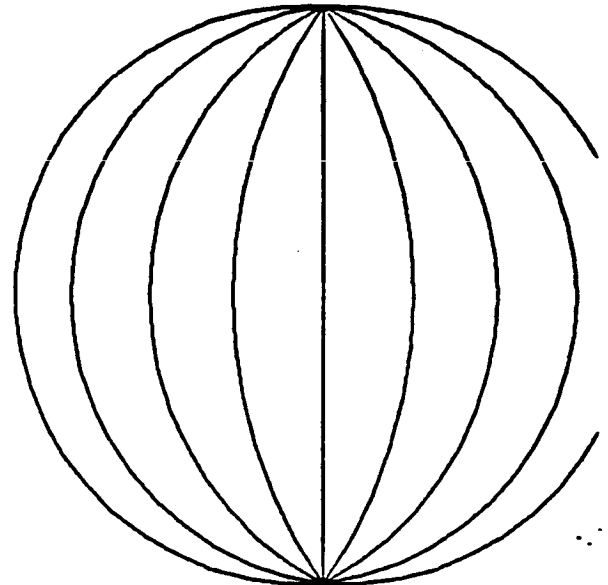


Top View

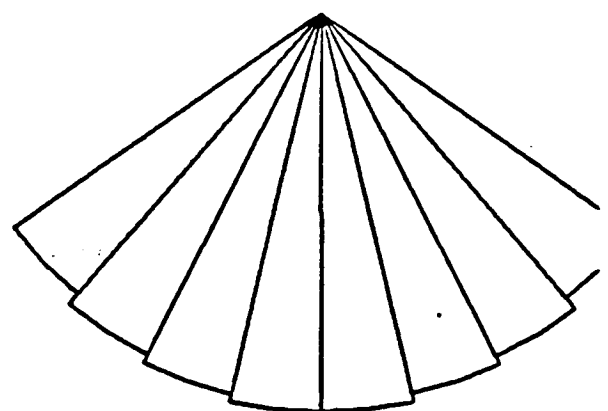


Side View

Opened



Top View



Side View

FIGURE 4.12

The first design option for an elastic cable is rubber, or bungee chord. Rubber has a low spring constant, plus it is inexpensive and does not corrode. A disadvantage of rubber is its non-linearity in displacement. For the same load, rubber varies in the amount of displacement. In arrangements of more than one cable, control is almost impossible, especially if the cables are reacting differently to applied loads. Another disadvantage is that rubber is weak and may give out under the stress of the test.

A second design option is using springs for the elastic cables. Springs have the advantage of being versatile. Whichever spring constant is needed, a spring can be fabricated to match. Springs also have the advantage of being durable. However, since most springs are made of metal, they corrode in a water environment.

The last design option for an elastic cable is light monofilament. An example of this is light fishing line and has the advantages of being inexpensive and easy to work with. Light fishing line has the disadvantage of more rapidly progressing to plastic deformation when overextended.

Since the tests must be as variable as possible to obtain an optimal arrangement, the cables must vary in elasticity. By testing a range of stiff and elastic cables, a wide range of possible solutions can be tried.

## 27.5 Mathematical Model

The design requirement for accuracy in modeling the stabilization system implies a method of quantifying the similitude of the model to the real ACRV. This requirement necessitates a mathematical description of the system. Thus, the construction and subsequent testing of the ACRV Stabilization System must be accompanied by the construction and testing of a mathematical model of the system. There are four reasons for an accurate mathematical description of the system. First, the model must be shown to have validity in relation to the actual ACRV. To demonstrate the validity of the physical model, it is necessary to demonstrate that the reduced dimensions of the model correlate to the dimensions of the real ACRV. Second, the mathematical model is necessary to dictate the test conditions. Wave forms and frequencies must be produced such that they have the proper scaling relationship with the model. Third, a mathematical model indicates which material properties may best assist in the damping of the model's wave motion response. For instance, by allowing for a certain stiffness and mass in the mathematical model, the theoretical required damping can be calculated. Finally, the mathematical model allows the quantification of the test results and estimated experimental error, thus allowing the results of the model test to be applied to the real ACRV.

The mathematical model has several possible options. Choosing a math model involves decisions concerning accuracy, applicability, and assumptions. More accuracy leads

to more calculations; oversimplification tends to make the math less applicable to the reality. Incorrect assumptions can lead modelling astray.

Two mathematical models have been identified which could mathematically simulate the ACRV model. The math models are similar in appearance and differ in the approach taken to simplify the calculations. The first model is a second order non-homogeneous differential equation with linear coefficients [22]:

$$m \frac{d^2x}{dt^2} + c \frac{dx}{dt} + kx = F(x) \quad (6)$$

where:

- $x$  = linear displacement
- $m$  = the mass of the entire ACRV
- $c$  = the damping created by the DUPS
- $k$  = the spring constant caused by:
  - the buoyancy of the system
  - the elasticity of the cables
  - the elasticity of the attitude ring
- $F(x)$  = the buoyant force caused by the periodic wave motion

The above equation is a general vibration equation used to describe many phenomena. The advantage in using this equation is that it is relatively easy to derive the steady-state solution. The simplicity of the equation, however, is deceiving. Although the solution is apparently simple, the factors listed below the equation introduce the disadvantages in its use. For instance, the buoyant force caused by the wave motion becomes very complex, especially as the ACRV model begins to span more wavelengths. Additionally, the variable  $x$  becomes a vector as the model's degrees of freedom increase.

Another model under consideration uses the same differential form but uses the results of Yeung [23] in graphic form for the coefficients of the equation:

$$F_y = -\mu_{yy} \ddot{\alpha}(t) - \lambda_{yy} \dot{\alpha}(t) \quad (7)$$

where:

- $\alpha(t)$  = amplitude of the model's motion
- $\mu_{yy}$  = the added-mass coefficient
- $\lambda_{yy}$  = the damping coefficient

Since Yeung gives graphical data for  $\mu_{yy}$  and  $\lambda_{yy}$ , this equation can be solved with greater ease than the general form above. However, this equation gives only  $F_y$ , the hydrodynamic force in the vertical direction (heave).

While these two mathematical models present simulations of the ACRV models' motion, continuing research to find a finite-element numerical solution is recommended.

## Chapter 28.0      TEST EQUIPMENT

The objective of the test equipment is to measure the model's response to the wave excitation. Measurement of the model's vibrational frequency response is of prime interest. The frequency response can be measured in three ways. First, the linear displacement can be measured and the data differentiated to obtain the vibrational motion. Second, the vibrations of the model can be measured directly. Finally, the accelerations of the model can be measured and the data integrated to obtain vibrational characteristics.

### 28.1 Linear Measurement Devices

Possible linear measurement systems include LVDT/LVRT's (Linear Variable Differential Transformer/Linear Variable Reluctance Transducer), remote sensing such as a "viewer grid", a video camera, or a laser triangulation camera.

The LVDT/LVRT's are position-to-electrical transducers whose output is proportional to the position of a moveable magnetic core. The major advantages of an LVDT/LVRT are: high accuracy, sensitivity and linearity in position detection, frictionless operation, and durability. A major disadvantage is that one end of the LVDT/LVRT must be fixed. This requires a supporting structure mounted above or below the model (Figure 4.13). Additionally, since the LVDT/LVRT is a collar on a rod with inductive coils in the collar, it would need to be encased in a waterproof container as long as the range of motion expected, approximately 20 inches. Another disadvantage of the LVDT/LVRT centers around its physical size. The size of one that is used to measure the 20 inches of displacement may be too large to be accommodated in the ACRV model [24].

Another position measuring alternative is the "viewer grid" system. This system involves a grid marked on a window through which the model could be observed. As the model moved, the observer could mark its position at regular time intervals [25]. An advantage is that the model's response is directly observed. A disadvantage is the inherent inaccuracy in human response. Also, the grid needs to be partially submerged in the test pool to capture the full range of the model's motion. An enhancement to this system would be the addition of a video or film camera. With a partially submerged camera, the test engineers could play back a videotape frame by frame, carefully marking the model's position model for every frame on a grid drawn on the TV screen. In this manner, the test engineers would gain the advantage of directly observing the model's response while eliminating the human response error. However, the camera would need to be partially

## LVDT TEST OPTION

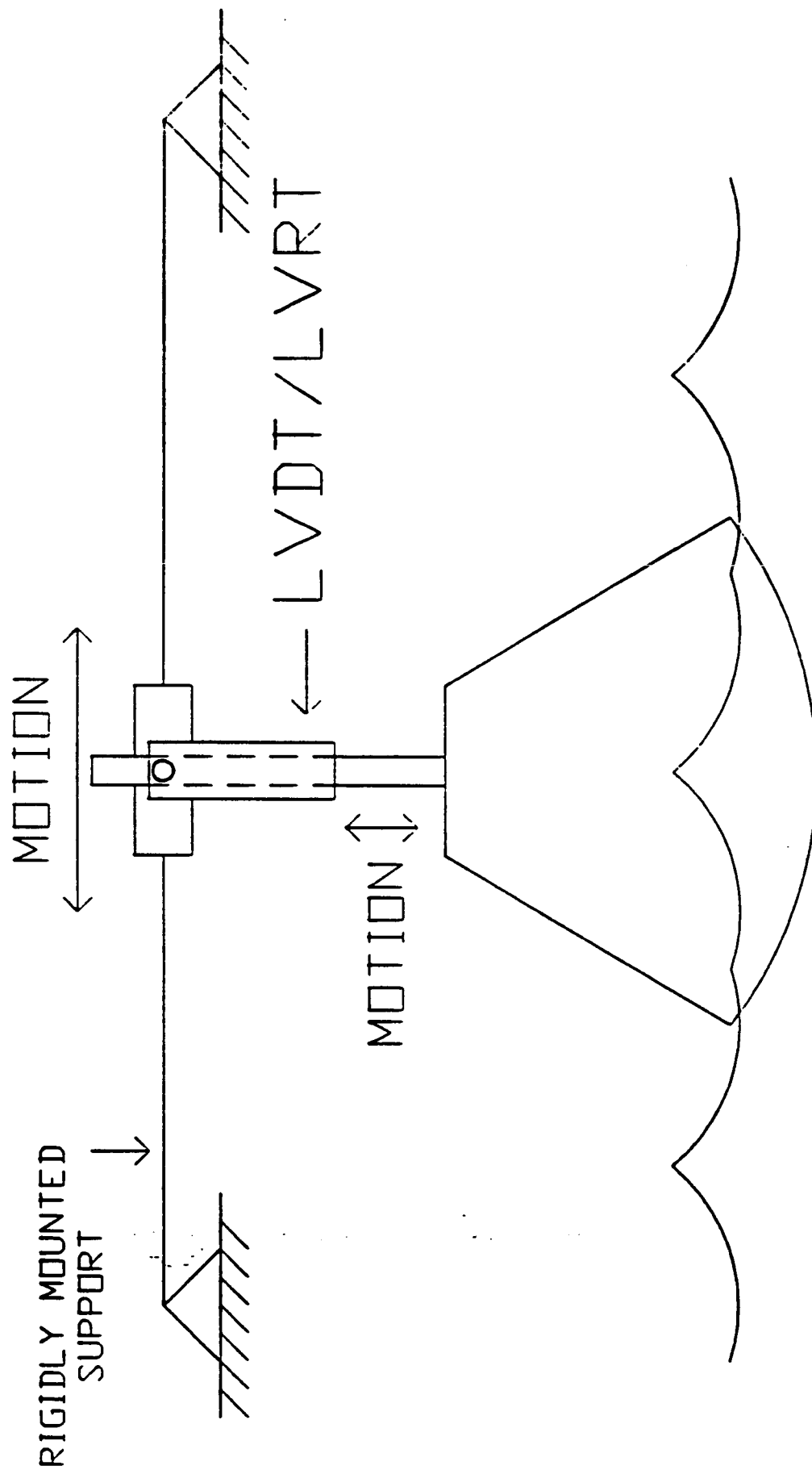


FIGURE 4.13

submerged to record the model's total response and thus be subject to the buffeting action of the waves. To maintain accuracy of the grid, the camera must be mounted rigidly.

The last position measuring device considered is the laser, or radar triangulation camera. This device involves a laser or radar signal sender with an offset receiver. By calculating the time required for the signal to hit the model and be received by the device, it accurately measures the distance to the object. The major advantage for this device is that it can be placed at a distance from the model and have a negligible effect on the experiments. A disadvantage is that a device of this type is complex since the device would have to track the model as it traversed the test pool (Figure 4.14).

## 28.2 Vibration Measurement Devices

Vibrometers are a type of seismic transducer, sometimes referred to as a seismometer. They are designed so that their natural frequency is low compared with the frequency of the vibratory motion to be measured. An advantage of the vibrometer is that the vibrational response is read directly without any further calculation.

The useable frequency range of a vibrometer depends upon its natural frequency, the damping present, and the accuracy desired in the approximation of displacement and acceleration. Without some type of damping mechanism, in addition to the damping inherent in the vibrometer, its natural frequency should be no greater than one-third the frequency of the system being measured. A vibrometer required to measure a frequency of 0.2 to 0.5 Hz would be at a natural frequency of .1667 Hz. Since the natural frequency of the vibrometer is inversely proportional to the square root of its mass, the vibrometer required to measure such a low frequency is massive (at least 10% of the model's weight) [22]. This fact illustrates a major disadvantage in using a vibrometer, as the addition of weight would affect the accuracy of the model.

## 28.3 Acceleration Measurement Devices

Accelerometers are designed in two concepts; one is designed by attaching a mass to a cantilever beam and the other is by placing a mass on a piezoelectric material. Both systems operate under the relationship of force equals mass times acceleration. The cantilever beam has force transducers (strain gages) attached to it that measure the force due to an accelerating mass. The piezoelectric accelerometer uses a piezoelectric material between the support base and mass. This material generates an electric charge when stressed. This electric charge is directly proportional to the force. The difference between the two is the piezoelectric accelerometer does not require an outside volt source for operation. Accelerometers are small in size (typically 0.25 to 0.75 in. diameter) and light weight (typically 0.2 to 20 grams). This permits their use in lightweight test objects without appreciably affecting the vibration characteristics measured [22].



## LASER TRIANGULATION OPTION

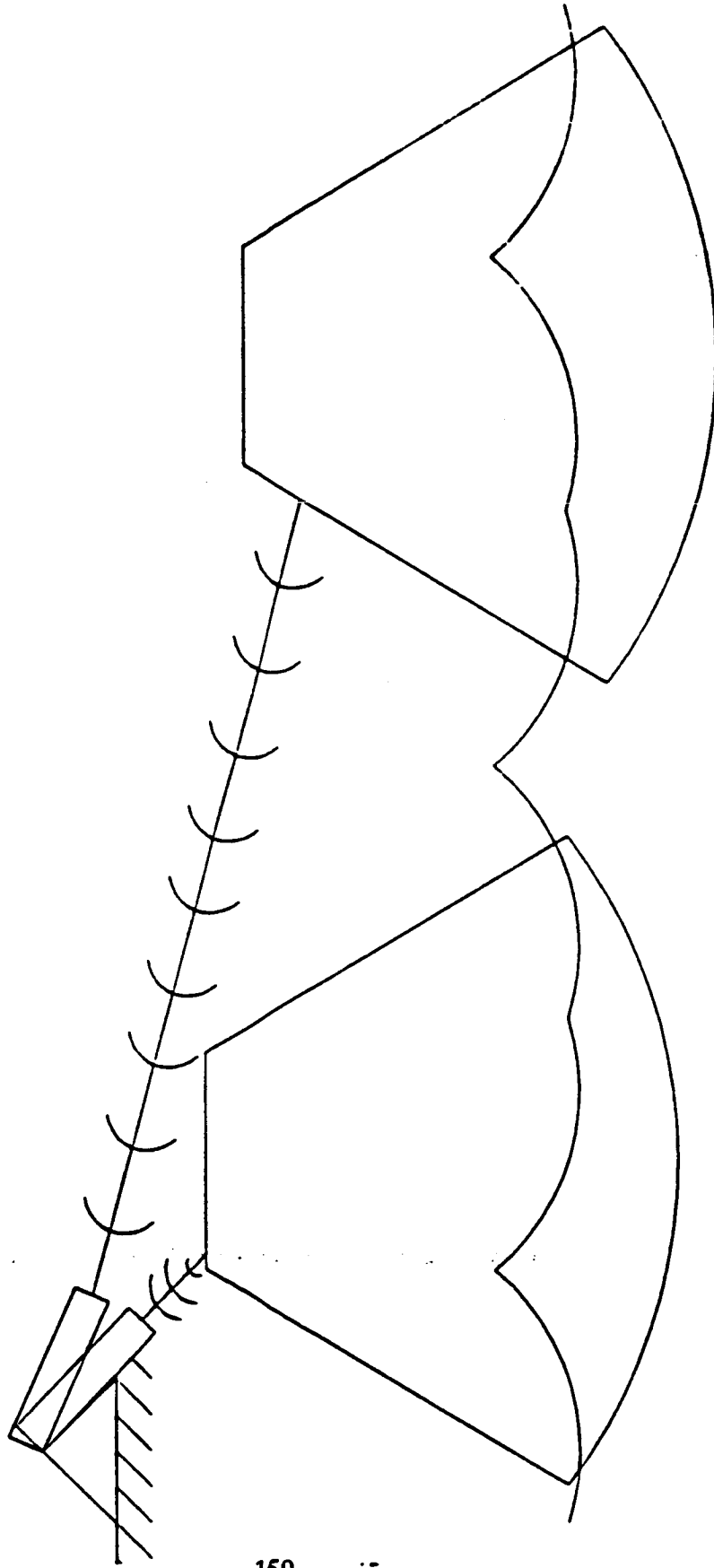


FIGURE 4.14

Accelerometers are designed to measure high frequencies. The range given in their specifications goes down to 10 Hz with an approximate error of 2.0%. This error does not restrict applying them to the ACRV model. The accelerometers can be individually calibrated to the lower frequency ranges by vibrating them at a known frequency input then measuring their response with an oscilloscope. In this manner, the accuracy of each accelerometer at low frequencies can be determined and a percent error calculated. This method should allow the use of available accelerometers with minimal error.

Most of the devices described above are electronically or manually entered into a computer database for analysis. The electronic data transfer capability is attractive since these tests will need to be conducted quickly, and the data sorted and reduced at a later date.

## Chapter 29.0      SUMMARY

Various design alternatives have been presented for each of the four fundamental areas of the ACRV model. From this point, the choices are narrowed such that: the Attitude Ring model is constrained to accurately model the proposed attitude ring. The Deployable Underwater Parachute System (DUPS) remains variable. The mathematical model predicts model behavior and similitude. The test equipment responds accurately. With those constraints on the design, the alternatives are sorted through until the optimal design solution has been decided and specified.

## Chapter 30.0      OPTIMAL SOLUTION - ACRV STABILIZATION CONTROL SYSTEMS

This section presents the chosen optimal designs for the ACRV Stabilization Control Systems effort. Chosen alternatives are presented in this section, including the criteria on which the decisions are based. Decision matrices 4.1 - 4.4 (Appendix H) were formulated to aid in the decisions.

The optimal solution process for each design consideration involved different design parameters for each. For the Attitude Ring, similitude to the anticipated design of the actual ACRV Attitude Ring is important. The Deployable Underwater Parachute System (DUPS) is a new concept, and thus has no previous design to follow. For this reason, the DUPS is designed to cover a wide range of configurations. The test equipment is chosen primarily on the basis of what is expected in the tests and what equipment is available. The mathematical model is chosen for the ease with which it makes the motion of the ACRV predictable and understandable.

### 30.1 Attitude Ring

The design of the actual ACRV attitude ring is anticipated to be similar to the ring used during Apollo recovery missions. For this reason, the model's attitude ring closely approximates this configuration. The five design options investigated were:

1. Styrofoam Ring
2. Rubber (Inner Tube) Ring
3. Balsa Wood Ring
4. Covered Foam Rubber Ring
5. Inflatable Spheres

The inflatable spheres design for the attitude ring was chosen as the optimal design. The spheres surpassed in the areas of cost, construction, integration, and safety. Another notable advantage over the other options is that the spheres allowed the demonstration of redundancy with no additional construction required. The use of spheres enables the ring to be more versatile than other design options considered. For instance, if weight limits were to be imposed upon the model, the addition or deletion of spheres allows for quick adjustment of the buoyancy required. The other four design options do not allow for this versatility. Tether balls, which come equipped with an attachment ring, are the correct size for the model. A more economical but less practical approach is to use volleyballs wrapped in nets.

Individual spheres can be deployed as "point buoyancy" sources. Since DUPS is deployed about the perimeter of the model at a discrete number of attachment points, attaching the spheres at the same points enables the math model to be restricted to the primary variables of concern. Specifically, using a continuous flotation ring around the model introduces moments caused by buoyant forces between the attachment points that complicate the model. While this complication may be a more accurate representation of the actual ACRV, the ability to demonstrate the feasibility of a stabilization system is well served by the inflatable spheres.

Concern has been expressed by NASA personnel as to the ability of the spheres to simulate the actual proposed ACRV attitude ring [26]. The concern is that a series of spheres may not model a continuous ring. For this reason, it may be necessary to demonstrate the stabilization system in conjunction with an actual attitude ring. Therefore, the second chosen alternative, the inner tube ring, may need to be substituted for the inflatable spheres. The inner tube ring is necessary if the stabilization system shows promise of being feasible. In other words, if the model using the spheres cannot be stabilized, then construction of the more complex model using the inner ring is unnecessary. The inflatable ring uses a rubber inner tube with canvas covering as the model attitude ring. This design option is also cost effective. To achieve redundancy however, a multi-chambered ring needs to be constructed, thus increasing costs.

## **30.2 Deployable Underwater Parachute System (DUPS)**

The objective of the DUPS concept is to dampen the vibrational wave response of the ACRV model. To dampen cyclic vibrations of the ocean waves, the parachutes must respond to the ACRV's motion. This means that the parachutes must provide damping (drag). As the ACRV travels up a wave (the upstroke), the parachutes open and provide a drag force similar to a dashpot. On the downstroke (as the model travels down the wave), the DUPS must have a lower coefficient of drag to sink with the ACRV. The fabric parachute is the optimal design option for this consideration since it collapses on the downstroke. The parachutes must sink with the ACRV so no slack is in the cables. With no slack in the cable, the parachutes are ready to dampen the ACRV motion at the beginning of each upstroke. To sink parachutes, a point mass is attached to the bottom of each parachute.

For the Deployable Underwater Parachute System the following four design options are considered:

1. Fabric Parachute
2. Hinged Plates
3. Spring Umbrella
4. Davis Instruments "Rocker Stopper"

The fabric parachute has advantages above the other systems with regards to design flexibility, weight, and cost. Although the Rocker Stopper is the best design option when considering maintainability and ease of construction, this design is not versatile.

Since DUPS is a new concept and has no prototype on which to base a model, the configuration must be versatile. This allows different system configurations to be tested. Experimenting with a range of configurations provides data to prove or disprove the feasibility of the stabilization system. Different configurations include parachutes of different diameters. Several fabric parachutes, each of different diameters, can be manufactured and tested.

Weight of the individual parachutes was another factor in determining the optimal design option. The parachute assembly must be heavy enough to follow the model on the downstroke, but not sink the model or be disproportionately massive. The parachute assemblies must weigh less than the model to approximate any anticipated actual design. Considering the actual ACRV, the material used to make the full-scale DUPS must be lightweight to minimize flight weight. A fabric parachute is the lightest design option.

Another decision factor was cost. When considering the necessity of different size parachutes, the fabric parachute is lower in cost (\$60.00 each) compared to all others except Rocker Stoppers. For the one-fifth scale model, fabric parachutes of 1, 2, and 3 feet in diameter will be used. Parachutes of these diameters are known as pilot chutes. Pilot

chutes are the smaller, spring-loaded chutes that deploy an actual parachute. The configurations to be tested require the purchase of three parachutes of each diameter. The estimated total cost for all of the parachutes including spares is \$700.00.

Fabric parachute design must take into account inflation time. Inflation time is the time needed to fully open the parachute [27]. Experiments have shown that the inflation time for a 3 foot diameter pilot chute in water is better than that in air however, the inflation time is still too long to sufficiently open within the model's vertical movement (approximately 1.2 feet). The inflation time is improved by fixing a rigid ring to the canopy.

A pilot chute contains a rigid ring at the peak of the canopy to decrease the inflation time. On a 3 foot diameter pilot chute, the ring is approximately 5 to 6 inches in diameter. The inflation time depends on the diameter of the ring. An appropriate ring diameter must be derived for each parachute diameter. This derivation is accomplished experimentally by attaching rigid, plastic rings of different diameters to the canopy of the parachute with velcro straps and determining the inflation time.

Besides fabric parachutes, testing configurations also include Rocker Stoppers. The Rocker Stoppers are included because they are inexpensive (\$6.00 each) and are proven to work on sailboats. However, the main part of the test is focused on the fabric parachute (pilot chute) due to its flexibility in diameter and drag force.

### 30.3 Cables and Attachments

To attach the parachutes to the model, two types of cable were considered: stiff and elastic. Since the objective is to design a vibration stabilization system using DUPS as a dashpot, the introduction of a spring into the system may be important. A logical place to insert a spring is between the dashpot (DUPS) and the mass to be dampened (ACRV model). For the spring, an elastic cable will be available for testing. However, the introduction of elasticity in the cable may be a detriment to stabilization, thus a stiff cable will also be provided. To test the necessity for elasticity in the cables, only the extremes of stiff and elastic must be provided. Parallel combinations of elastic material can be installed on the test model to allow for a full range of elasticity. Hence, it was necessary to choose only one type of stiff material and elastic material.

The three design options for the stiff cable were:

1. Steel
2. Graphite
3. Heavy Monofilament

The steel cable design was selected. The steel cable is superior in several of the design parameter categories including cost, reliability, and construction. The steel is also

easily repaired and has a high modulus of elasticity. As a guideline for the calculations, a steel cable that deflected less than 0.100 inches over a length of three feet would be 0.055 inches in diameter. The exact lengths of the cables needed to provide an optimum solution are determined during testing. The cables need to be long so that the surface waves do not affect the parachute motion but short enough to avoid interference with the bottom of the test pool. Thus, a spool of the specified cable is provided so that the lengths of the cables can be changed between experiments.

The three design options for the elastic cable are:

1. Rubber
2. Light Monofilament
3. Spring

The rubber cable design was chosen as the optimal design for the elastic cable. The other design options were determined to not be able to survive the test environment. Rubber is the only design option that provided the elasticity and non-corrosive properties needed. The rubber cable used is similar to a bungee cord. Since the exact length and elasticity needed are not known, a variety of lengths are provided for the tests.

The type of attachment used to connect the parachutes to the eye bolt on the model is a carabinier (Figure 4.15). The carabiniers provide quick and easy removal and replacement of the parachutes and cables. Each end of the cable is attached to a carabinier by looping the cable through a lead clasp to form a loop then crimping the clasp and cable together.

### 30.4 Mathematical Model

The mathematical model employed to predict and describe the response of the ACRV model to the wave motion is a second order non-homogeneous differential equation with linear coefficients. This model was chosen over Yeung's model [23] because the Yeung model cannot account for the elasticity of the cables and the attitude ring. The chosen equation is: [22]

$$m \frac{d^2x}{dt^2} + c \frac{dx}{dt} + kx = F(x) \quad (8)$$

where:

- $x$  = linear displacement
- $m$  = the mass of the entire ACRV
- $c$  = the damping created by the DUPS
- $k$  = the spring constant caused by:
  - the buoyancy of the system

## CARABINIER ATTACHMENTS AT THE ENDS OF A CABLE

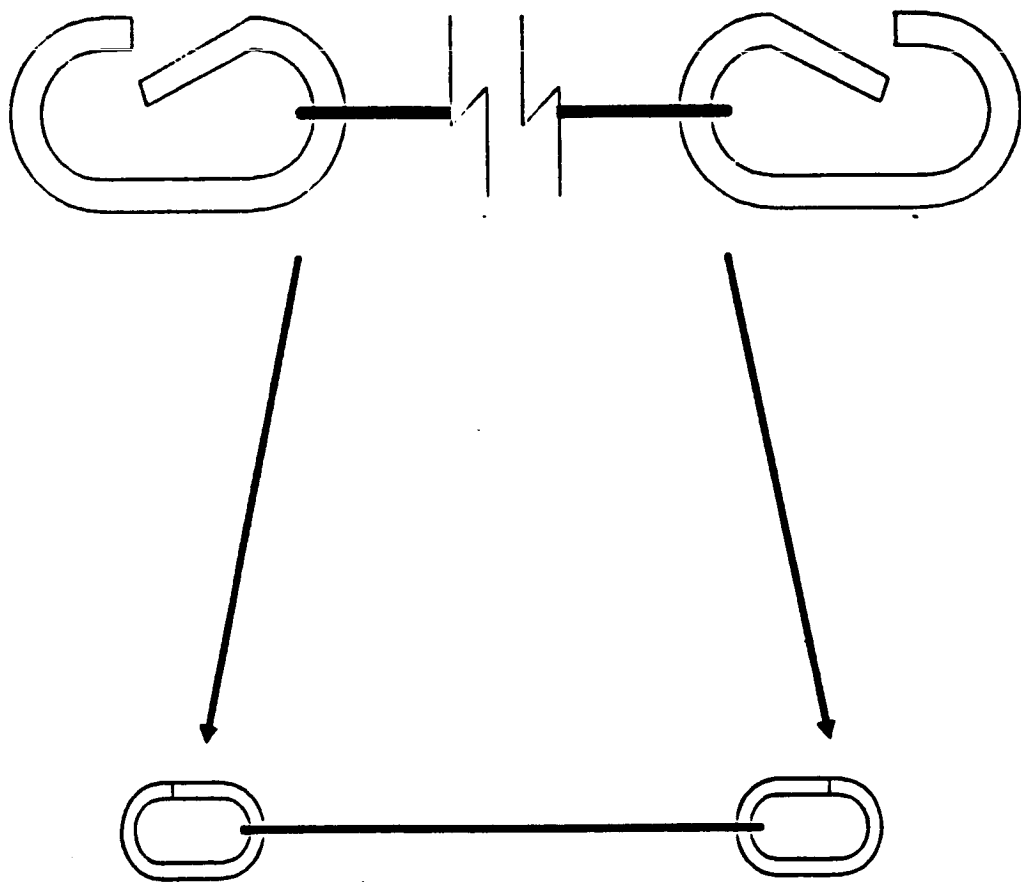


FIGURE 4.15

- the elasticity of the cables
  - the elasticity of the attitude ring
- $F(x)$  = the buoyant force caused by the  
periodic wave motion

The steady-state solution for this model is not difficult to find for the sinusoidal forcing function (the test waves). By using matrices for the constant coefficients of  $m$ ,  $c$ , and  $k$ ; the model can be gradually expanded to include multiple degrees of freedom as well as multiple dimensions as the testing conditions increase in complexity. This model can be used to describe the simplest case where the ACRV model is placed in a standing wave with one suspended parachute resulting in two degrees of freedom along one dimension. The model can also be used to describe a case where the ACRV model with three parachutes is placed in a wave with three dimensional geometry resulting in nine degrees of freedom in three dimensions. This mathematical model is complex, but a finite element computer code will be used to simplify calculations.

### 30.5 Test Equipment

Test equipment will be used to measure and record the frequency response of the model. Possible alternatives for test equipment are broken down into two categories: contact and non-contact. Contact equipment is attached directly to the model while non-contact equipment is separate from the model and obtains data by remote sensing. The obvious advantage of non-contact equipment is that it has no effect on the experimentation. However, remote sensing is much less accurate.

The test equipment was chosen primarily on the basis of what is expected in the testing environment and what equipment is available. The design options for the contact equipment are:

1. LVDT
2. Vibrometer
3. Accelerometer

The accelerometer is the best design option for measuring the vibrational frequency of the model. Disadvantages of the LVDT are its large size and that it requires a gantry which obstructs the motion of the model. The major disadvantage of the vibrometer is its large mass. The accelerometer has the ability to measure the low frequency with a high accuracy, and it is small and light. Two types of accelerometers are being considered: seismic and shock. The seismic accelerometer offers an error of 5% for the frequency range of 0.025 to 800 Hz and weighs approximately two pounds. The shock accelerometer has an error of 5% for frequency range of 0.05 to 5000 Hz and weighs approximately 1.0 oz. The seismic accelerometer costs \$480.00 and the shock accelerometer costs \$295.00. Each accelerometer is connected to a computer through an Analog to Digital board. An oscilloscope can be



connected to the accelerometers allowing the model's response to be viewed in real time. The acceleration data can be integrated by the computer to give the vibrational response.

The design options for the non-contact equipment are:

1. Laser Triangulation
2. Video Camera
3. Manual View Grid

The video camera was chosen to be the best design option for the non-contact equipment. Use of laser triangulation is too costly. The manual view grid offers many possibilities for human error. The video camera with a grid allows for recorded visualization, as well as viewing the model during testing. Since the inflation cycle of the parachutes is critical to the performance of the system, a visual record of the its response improves the amount of data for analyzing the system. If this system does not operate properly for a certain configuration, new configurations will be used until the system functions correctly.

Through optimizing the design options with a decision matrix, the best approach to testing was found. By using accelerometers and a video camera with a grid, data can be taken and recorded for analysis of the physical model with the mathematical model.

## **Chapter 31.0      OBSERVATIONS AND RECOMMENDATIONS**

During the research, design, and experimentation detailed in this report, observations were noted that led to recommendations for the next phase of this project: the building and testing phase.

Several important recommendations pertain to how the testing should be carried out. Since the system configuration can rapidly increase in complexity, the testing team may want to start with a simple DUPS arrangement and standing wave excitation on the model. This approach will allow the test equipment and the mathematical model to be tested for accuracy. The standing wave will produce motion in the vertical direction only and when used on a DUPS configuration of only one parachute results in a mathematical model in its simplest form. In fact, a tether ball attached to a parachute will be the simplest way to visualize the test response. This simplicity in the initial testing allows the test engineers to ascertain the viability of the accelerometers, analog to digital board, and mathematical model. If the components of the physical model react differently to the standing wave than that predicted by the mathematical model, the mathematical model must be changed. The same applies to the test equipment. If the measured response is different from the predicted response, then the test equipment may be in error.

Once the response of the test equipment has been verified, DUPS arrangement can be increased in complexity. However, since each added elastic cable adds a degree of freedom, the test engineers may want to attach parachutes with stiff cables. Once the parachute has been observed to be predictable, the stiff cable can be replaced with an elastic cable and re-tested. In this manner, the system complexity can be gradually increased and the mathematical model veracity can be confirmed. In the same way, the parachute size should be varied in gradual increments. In other words, it is recommended that the ACRV model not be simply placed in the water with a complex DUPS arrangement aboard. Rather, the test configurations should be gradually increased in complexity. The final arrangement of the stabilization system should be three lines of DUPS with three 3 ft diameter parachutes in series.

Another recommendation is that the attitude ring first be modeled with the tether balls. This configuration will reduce the mathematical complexity of the model when compared to the continuous ring. However, the inner tube will be used to model and test a continuous ring configuration. The attitude ring also includes an extension for the rapid egress system. This extension can be constructed of styrofoam to the required dimensions and attached to the eye bolts when the rapid egress system needs to be tested. In conclusion, the test must be as variable as possible to obtain enough data to prove or disprove the feasibility of the stabilization system for the ACRV after a water landing.

## **BUILDING PHASE ACRV STABILIZATION CONTROL SYSTEMS**

### **Chapter 32.0      ATTITUDE RING CONSTRUCTION**

Refer to Figures 4.16 - 4.17 for a description of the work schedule and milestone chart for the attitude ring construction.

### **Chapter 33.0      ATTITUDE RING MATTRESS CONSTRUCTION**

Refer to Figures 4.18 - 4.19 for a description of the work schedule and milestone chart for the attitude ring mattress construction.

### **Chapter 34.0      UNDERWATER PARACHUTE CONSTRUCTION**

Refer to Figures 4.20 - 4.21 for a description of the work schedule and milestone chart for the underwater parachute construction.

### **Chapter 35.0      TESTBED CONSTRUCTION**

Refer to Figures 4.22 - 4.23 for a description of the work schedules and milestone chart for the testbed construction.

# ATTITUDE RING CONSTRUCTION SCHEDULE

## A.1 Review Requirements

- A.1.1 Requirements [1/7-1/20]
- A.1.2 Drawings [1/7-1/23]
- A.1.3 Physical Characteristics [1/7-1/30]

## A . 2

- A.2.1 Volume Calculations [1/9-2/6]
- A.2.2 Displacement Calculations [1/11-2/6]
- A.2.3 Attitude Ring Calculations [2/1-2/11]
- A.2.4 Dynamic Response Calc. [2/6-2/13]

## A.3 Drawings

- A.3.1 Sketches [2/1-2/11]
- A.3.2 Detailed Construction Drawings [2/11-2/20]

## A.4 Material Acquisition

- A.4.1 Construction Material [2/20-3/6]
- A.4.2 Construction Tools [2/20-3/6]
- A.4.3 Supplemental Material [2/20-3/6]

## A.5 Fabrication

- A.5.1 Attitude Ring Const. [2/27-3/11]
- A.5.2 Integration w/ Model [3/6-3/11]

## A.6 Pretest

- A.6.1 Initial Pretest [3/11-3/13]
- A.6.2 Repair and Modifications [3/13-3/15]
- A.6.3 Final Testing [3/15-3/18]

## A.7 Finishing

- A.7.1 Paint [3/15-3/18]
- A.7.2 Decal [3/15-3/18]

FIGURE 4.16

# ATTITUDE RING CONST. MILESTONE CHART

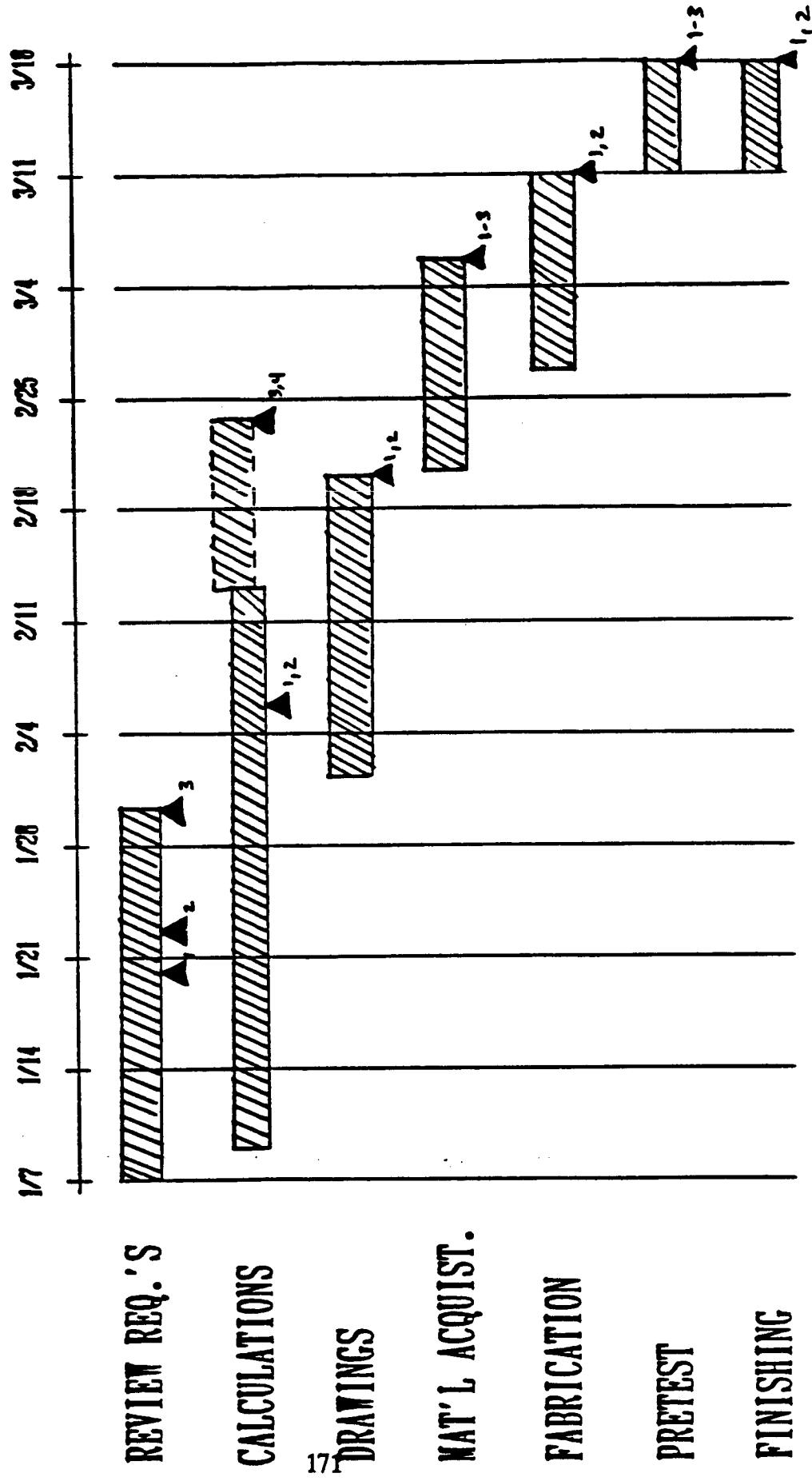


FIGURE 4.17

# MATTRESS CONSTRUCTION SCHEDULE

## B.1 Review Requirements

- B.1.1 Requirements [1/7-1/11]
- B.1.2 Drawings [1/14-1/28]
- B.1.3 Physical Characteristics [1/21-1/25]

## B . 2

- B.2.1 Physical Parameters [1/28-1/29]
- B.2.2 Dimensions [1/30-2/1]
- B.2.3 Attachments [1/30-2/3]
- B.2.4 Force/Moment Calc. [2/4-2/7]

## B.3 Drawings

- B.3.1 Sketches [2/8-2/10]
- B.3.2 Detailed Construction Drawings [2/9-2/12]

## B.4 Material Acquisition

- B.4.1 Purchasing [2/13-2/15]
- B.4.2 Modifications [2/18-2/21]

## B.5 Fabrication

- B.5.1 Mattress Const. [2/19-3/11]
- B.5.2 System Integration [2/15-3/11]

## B.6 Pretest

- B.6.1 Integration Acceptance [2/22-3/11]
- B.6.2 Rework [2/28-3/11]

## B.7 Finishing

- B.7.1 Paint [3/11-3/18]
- B.7.2 Decal [3/11-3/18]

FIGURE 4.18

# MATTRESS CONSTRUCTION MILESTONE CHART

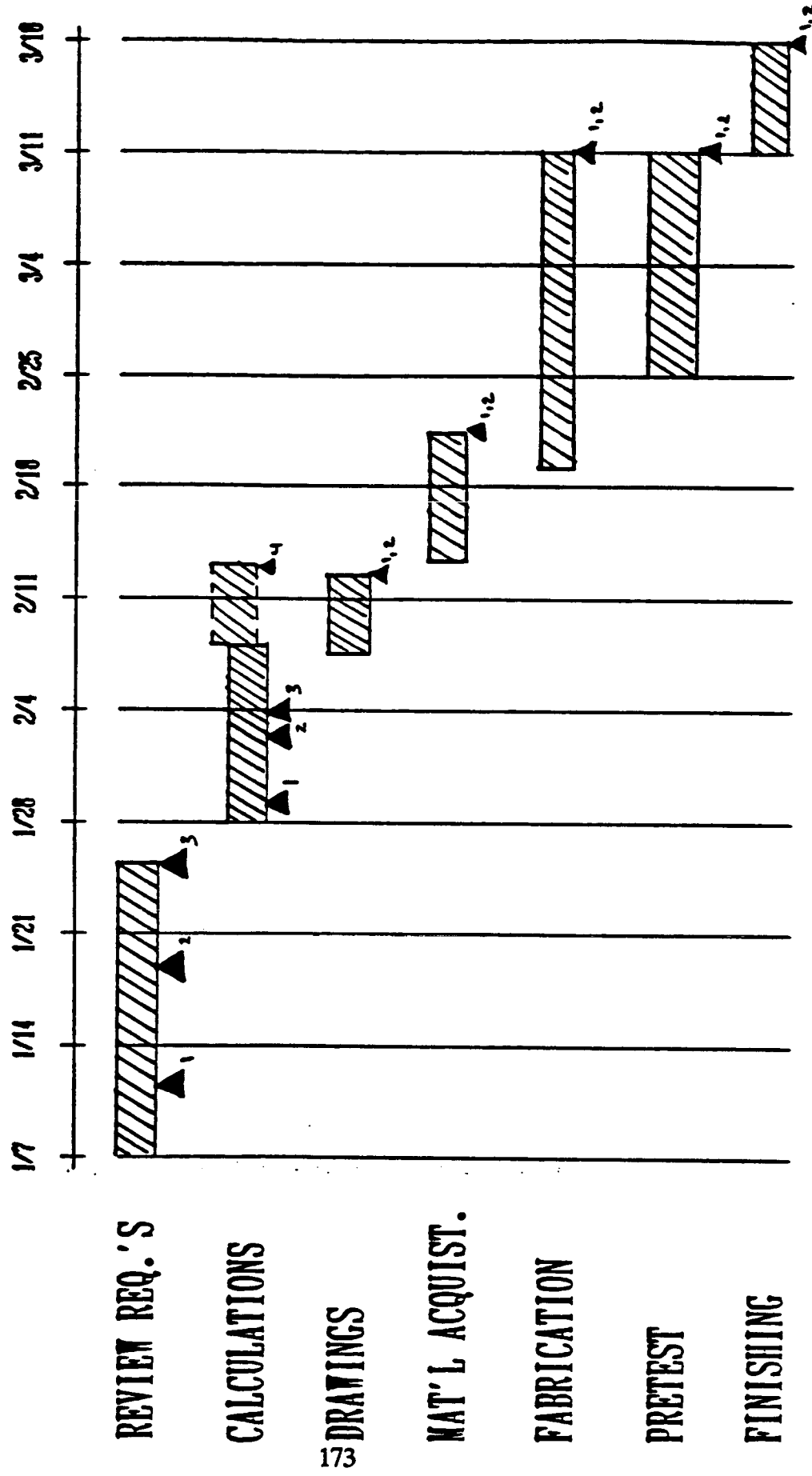


FIGURE 4.19

# PARACHUTE CONSTRUCTION SCHEDULE

## C.1 Review Requirements

- C.1.1 Requirements [1/7-1/21]
- C.1.2 Drawings [1/7-1/21]
- C.1.3 Physical Characteristics [1/21-2/11]

## C.2

- C.2.1 Physical Parameters [1/31-2/11]
- C.2.2 Dynamic Similitude [1/31-2/11]

## C.3 Drawings

- C.3.1 Sketches [1/28-2/11]
- C.3.2 Detailed Construction Drawings [2/1-2/11]

## C.4 Material Acquisition

- C.4.1 Construction Materials [1/31-2/11]
- C.4.2 Construction Tools [2/4-3/4]

## C.5 Fabrication

- C.5.1 Parachute Const. [2/11-3/11]
- C.5.2 Cable & Attachment [2/18-3/11]

## C.6 Pretest

- C.6.1 Parachute Performance [2/18-3/11]
- C.6.2 Cable & Attachment Perf [2/18-3/11]

## C.7 Finishing

- C.7.1 Packaging [3/11-3/18]

FIGURE 4.20



# PARACHUTE CONSTRUCTION MILESTONE CHART

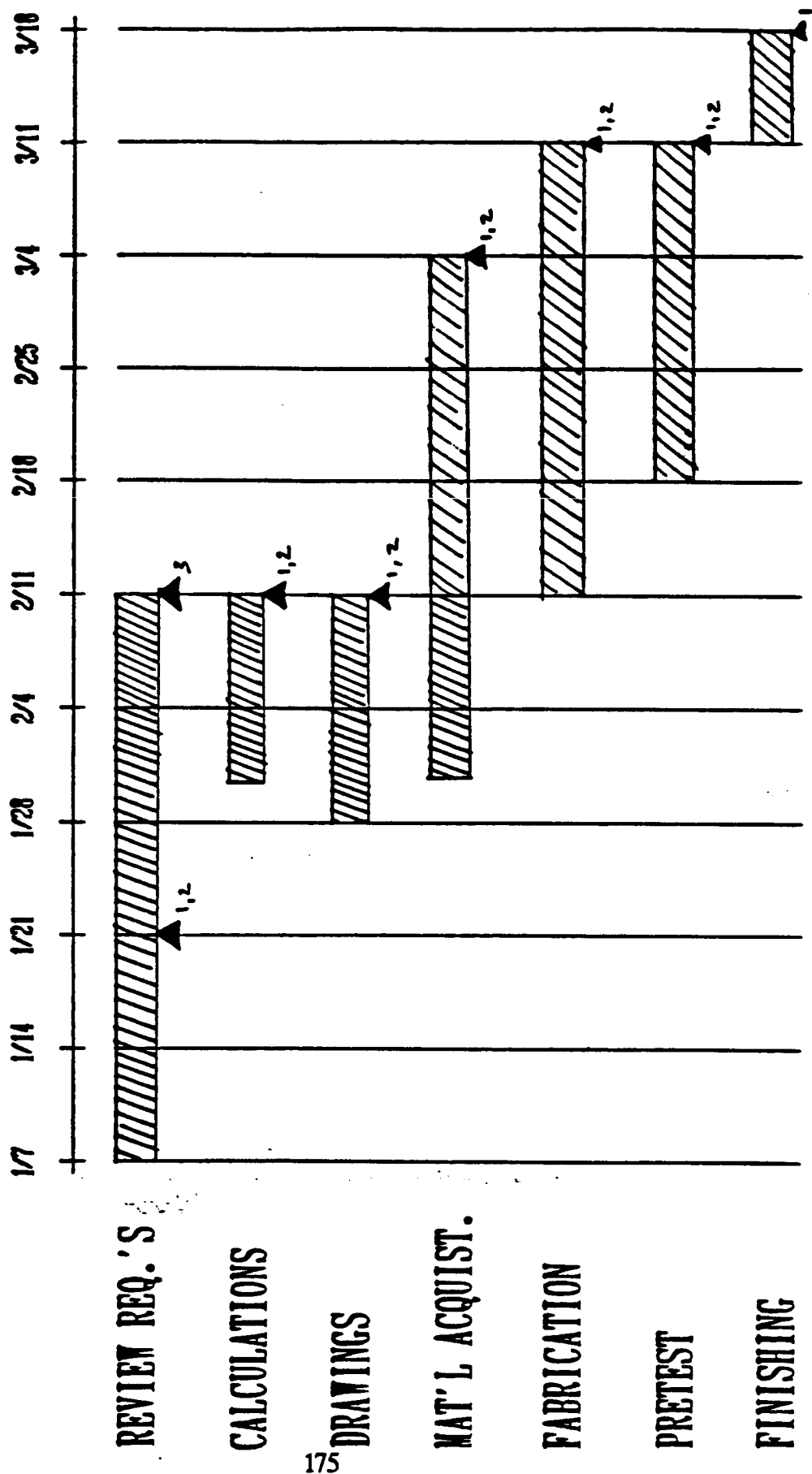


FIGURE 4.21

# TESTBED CONSTRUCTION SCHEDULE

## D.1 Review Requirements

- D.1.1 Requirements [1/7-1/11]
- D.1.2 Drawings [1/11-1/18]
- D.1.3 Physical Characteristics [1/18-1/29]

## D.2

- D.2.1 Physical Dimensions [1/28-2/1]
- D.2.2 Cable/Attachment Calc. [1/30-2/1]

## D.3 Drawings

- D.3.1 Sketches [2/1-2/6]
- D.3.2 Detailed Construction Drawings [2/6-2/10]

## D.4 Material Acquisition

- D.4.1 Construction Materials [2/6-2/13]
- D.4.2 Construction Tools [2/6-2/13]

## D.5 Fabrication

- D.5.1 Testbed Const. [2/13-2/25]
- D.5.2 Testbed Integration w/ Model [2/18-2/25]

## D.6 Pretest

- D.6.1 Parachute Performance Validations [2/18-3/11]
- D.6.2 Cable & Attachment Perf [2/18-3/11]
- D.6.3 Miscellaneous Testing [2/25-3/11]

## D.7 Finishing [3/11-3/18]

FIGURE 4.22

# TESTBED CONSTRUCTION MILESTONE CHART

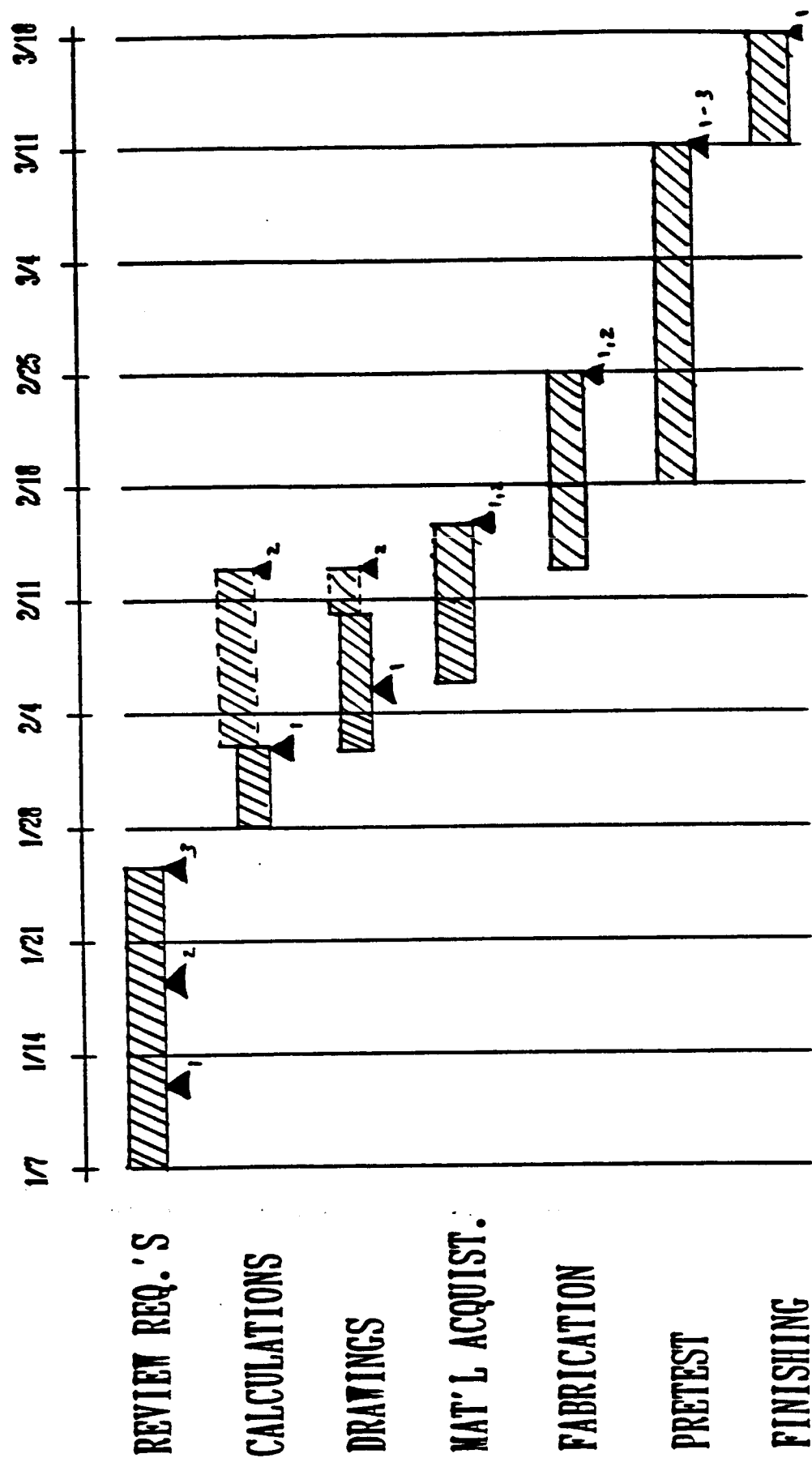


FIGURE 4.23

## **TESTING PHASE                      ACRV STABILIZATION CONTROL SYSTEMS**

### **Chapter 36.0                      TEST PLAN**

This test plan includes test objectives, procedures, and data collected applicable to the stabilization system. The test will be split into two sections. Section 36.1 is associated with pretesting the stabilization system components at the construction site prior to departure to the water testing facility. The pretests will be performed on a testbed which will be configured to simulate the hemispherical base and part of the upper shell of the ACRV model. Section 36.2 is associated with testing performed at the water facility using the actual ACRV model.

#### **36.1    Pretest**

##### **- Test #1**

**Objective:**            Verify attachment methods for both the attitude ring and mattress.

**Procedure:**        1.A:    Attitude Ring attachment verification.

                         1.A.1    Attach attitude ring to eye bolts on testbed.

                         1.A.2    Apply 12 pound force to ring in direction away from testbed.

                         1.A.3    Visually verify that attachment hooks operate properly.

                         1.A.4    Record findings.

                         1.B:    Mattress attachment verification.

                         1.B.1    Repeat 1.A.1 - 1.A.3 for mattress attachment.

**Data Collected:**    Attitude Ring and Mattress attachment procedures and acceptance.

##### **- Test #2**

**Objective:**            Verify Egress Extension Mechanism compatibility with Attitude Ring Mattress (ARM).

**Procedure:**        2.A:

                         2.A.1    Repeat test 1.A.1 - 1.A.2 of Rapid Egress Construction Team Test Plan.

- 2.A.2 Secure 6 pounds of weight on Egress System
- 2.A.3 Secure ARM (parallel to the ground) at a location which is equivalent to the bottom of the hatch opening.
- 2.A.4 Activate FLIPEM and TSSM.
- 2.A.5 Videotape activation procedure.
- 2.A.6 Check for interference between ARM and TSSM
- 2.A.7 Record findings.

Data Collected: Extension mechanism and ARM interference.

- Test #3

Objective: Verify water absorption properties of ARM material.

Procedure: 3.A:

- 3.A.1 Weigh ARM on a balance scale and record weight.
- 3.A.2 Submerge ARM in water for 5 minutes and remove.
- 3.A.3 Repeat procedure 3.A.1.
- 3.A.4 Record weight difference.

Data Collected: ARM absorption characteristics.

- Test #4

Objective: Verify properties of both elastic and inelastic parachute cables.

Procedure: 4.A: Elastic

- 4.A.1 Place elastic cable in a tensile stress machine.
- 4.A.2 Apply impulsive force up to 170 pounds.
- 4.A.3 Generate plots of stress versus strain.
- 4.A.4 Record findings.

4.B: Inelastic

- 4.B.1 Repeat procedures 4.A.1 - 4.A.4 for inelastic cables.

Data Collected: Stress and strain characteristics of cables.

**- Test #5**

**Objective:**      **Verify cable crimping method.**

**Procedure:**      **5.A:**

- 5.A.1**    **Place hook in one end of cable and attach to tensile machine.**
- 5.A.2**    **Apply 170 pound load to opposite end of cable, until failure.**
- 5.A.3**    **Record force required for failure and location of failure.**

**Data Collected:**    **Cable crimping acceptance.**

**- Test #6**

**Objective:**      **Verify attachment methods for cable system to testbed.**

**Procedure:**      **6.A:**

- 6.A.1**    **Repeat procedure 1.A.1 - 1.A.3 for cable system.**

**Data Collected;**    **Cable attachment procedures and acceptance.**

**- Test #7**

**Objective:**      **Verify parachute design integrity.**

**Procedure:**      **7.A:**

- 7.A.1**    **Apply variable pound force of up to 170 pounds in several directions to produce failure.**
- 7.A.2**    **Compare above force with theoretical force and record findings.**

**Data Collected:**    **Parachute acceptance**

- Test #8

**Objective:** Verify attachment procedures of the cables to the parachutes in series.

**Procedure:** 8.A:

8.A.1 Attach rapid connector link through crown lines of the uppermost parachute and secure to next cable.

8.A.2 Apply a 170 pound load to assembly.

8.A.3 Record findings.

**Data Collected:** Parachute/cable compatibility.

- Test #9

**Objective:** Visually document operation of the point mass system used to deflate parachutes on downstroke.

**Procedure:** 9.A:

9.A.1 Hold attachment end of parachute cable above water and place parachute and point mass system underwater.

9.A.2 Position video camera under water for optimum viewing.

9.A.3 Pull upward with adequate force to inflate parachute. Once parachute is inflated, cease force and let parachute deflate to original position.

9.A.4 Video tape procedure 9.A.3

**Data Collected:** Point mass capabilities.

- Test #10

**Objective:** Verify parachute inflation times.

**Procedure:** 10.A:

10.A.1 Use video tape from procedure 9.A.3 with stopwatch to determine inflation and deflation times separately.

10.A.2 Record times.

**Data Collected:** Parachute inflation and deflation times.

## 36.2 Tests at Water Facility

### - Test #11

**Objective:** Attach accelerometers and verify correct operation.

**Procedure:** 11.A:

11.A.1 Attach accelerometers in 3 locations. Two accelerometers shall be mounted in the center of the model's plywood floor, one in the horizontal direction and the other in the vertical. The third accelerometer shall be placed on the plywood floor near the hatch. Each accelerometer shall be attached to the floor with wood screws.

11.A.2 Connect to data acquisition system.

11.A.3 Verify proper operation of accelerometers.

**Data Collected:** Proper placement and operation of accelerometers.

### - Test #12

**Objective:** Establish baseline dynamic responses with "clean" model (no attachments).

**Procedure:** 12.A:

12.A.1 Verify proper operation of accelerometers in model.

12.A.2 Lower model into test tank and tether to prevent rotation and collision with test tank walls.

12.A.3 Activate wave machine to simulate sea state 2 at .2 to .5 Hertz.

12.A.4 Activate data acquisition system after steady state conditions have been reached.

12.A.5 Obtain data.

12.A.6 Repeat procedures 12.A.1 - 12.A.5 incrementing sea state by 1 to sea state 4.



- **Test #13**

**Objective:** Establish attitude ring (only) effects on model stabilization.

**Procedure:** 13.A:

13.A.1 Repeat procedures 12.A.1 - 12.A.6 with Attitude Ring (only) attached.

- **Test #14**

**Objective:** Establish ARM (only) effects on model stabilization.

**Procedure:** 14.A:

14.A.1 Repeat procedures 12.A.1 - 12.A.6 with ARM (only) attached.

- **Test #15**

**Objective:** Establish Attitude Ring and ARM combination effects on model stabilization.

**Procedure:** 15.A:

15.A.1 Repeat procedures 12.A.1 - 12.A.6 with Attitude Ring and ARM attached.

- **Test #16**

**Objective:** Establish parachute (only) effects on model stabilization (all possible configuration tested.)

**Procedure:** 16.A:

16.A.1 Repeat procedures 12.A.1 to 12.A.6 with parachutes (only) attached.

- Test #17

**Objective;**      Establish Attitude Ring and parachute combination effects on model stabilization.

**Procedure:**     17.A:

17.A.1 Repeat procedures 12.A.1 - 12.A.6 with Attitude Ring and parachutes attached.

**NOTE:**      Use the optimal parachute configuration resulting from Test #16.

- Test #18

**Objective:**      Establish Attitude Ring, ARM, and parachute combination effects on model stabilization.

**Procedure:**     18.A:

18.A.1 Repeat 12.A.1 - 12.A.6 with Attitude Ring, ARM and optimal parachute configuration attached.

Chapter 37.0 TEST DATA

TEST #1

1.A) Record findings

Eye bolts withstood expected loading. Industrial twist ties withstood a 16 pound load.

1.B) Record findings

Rapid connector links withstood the maximum expected load of 20 pounds at the ARM connection points. The 20 pound force is derived from the buoyancy effects of the ARM.

## TEST #2

### 2.A) Record findings

There was an approximate 0.25 inch vertical clearance between the ARM and the TSSM. No interference occurred.

## TEST #3

### 3.A) Weight of ARM before submersion 21 ounces.

Weight of ARM after submersion 22 ounces.

Difference 1 ounce.

## TEST #4

### 4.A) Record findings

See plot of stress versus strain in Appendix E.

### 4.B) Record findings

See plot of stress versus strain in Appendix E. NOTE: this data is from reference material (Shigley J. E., Mechanical Engineering Design, McGraw-Hill Book Company, New York, New York, 1989, p. 229)

## TEST #5

### 5.A) Load required for failure 14,800 pounds.

Failure location: mid-point of length

An approximate 170 pound load was applied. Failure did not occur. NOTE: data for plot was taken from reference material referred to in the data for Test #4.B.

## TEST #6

### 6.A) Record findings

Rapid connector links are factory rated at 1760 and 1900 pounds.

## TEST #7

### 7.A) Record findings

The apex of a 2 foot parachute was fixed, a 170 pound load was attached to the suspension lines with no resulting failure. Breakdown of the parachute was only achieved through application of a 20 pound load directly to the beginning of the primary seam.

## TEST #8

### 8.A) Record findings

Rapid connector links were inserted through crown lines of the top parachute and secured to the next cable. A 170 pound load was applied to this configuration without resulting failure.

## TEST #9

### 9.A) Record findings

Video equipment was acquired. Tests were run and recorded. Video was taken from above the water line, but suitable enough for viewing.

## TEST #10

Diameter	1 ft.	1.5 ft.	2 ft.	2.5 ft.
Inflation	2.0 s	2.1 s	2.2 s	5.3 s

Diameter	1 ft.	1.5 ft.	2 ft.	2.5 ft.
Deflation	1.1 s	2.6 s	2.7 s	5.5 s

## **Chapter 38.0 TEST RESULTS AND OBSERVATIONS**

This portion of the test report addresses the objective of each test performed along with the procedures used and data collected. Observations and recommendations are also given for each test.

### **- Test #1**

- 1.A:** Test 1.A was performed to determine the suitability and strength of the attitude ring attachment methods. Procedures 1.A.1 - 1.A.4 were followed. Inflatable spheres were used in place of a continuous ring.

The industrial twist-tie attachments were visually verified to support a load of 16 pounds. A determination was made that the twist ties would provide sufficient strength for ACRV testing.

- 1.B:** Test 1.B was performed to determine the suitability and strength of the mattress attachment methods. Procedures 1.A.1 - 1.A.3 were repeated for the mattress attachment. Two 1700 pound rapid connector links were used.

The 1700 pound rapid connector links were visually verified to support a load of 170 pounds. A decision was made that the rapid connector links would sustain any possible forces during normal ACRV testing without failure.

### **- Test #2**

- 2.A:** Test 2.A was performed to verify compatibility of the egress extension mechanism with the attitude ring mattress. Procedures 2.A.1 - 2.A.7 of the test plan were followed.

The mattress was determined visually to provide no hinderance to the Two Stage Slider Mechanism (TSSM) upon activation of the egress system. The mattress allowed for approximately 0.25 inch clearance below the TSSM system.

**- Test #3**

- 3.A:** Test 3.A was performed to verify water absorption properties of ARM material. Procedures 3.A.1 - 3.A.4 were followed. After submersion, excess water was allowed to drain such that only water absorbed by the material was retained in the ARM.

Before submersion, the ARM weighed approximately 21 ounces. Following submersion and draining, the ARM was found to have no significant increase in weight. This result was not unexpected as the ARM is constructed of sealed plastic bladders.

**- Test #4**

- 4.A:** Test 4.A was performed to verify the properties of elastic parachute cables. Rather than mount a sample of elastic cable in a tensile stress machine as suggested in procedures 4.A.1 - 4.A.4, a simple method of generating stress-strain diagrams was employed. The cable was fixed at one end and then a range of masses were attached to the other. Displacement of the cable was measured for each mass and the results were plotted.

The plot of stress versus strain is in Appendix E. The plot is nonlinear. However, the initial linear slope is almost horizontal; therefore, this cable is almost totally elastic.

- 4.B:** Test 4.B was performed to verify properties of inelastic parachute cables. Rather than follow the procedure outlined in 4.B.1, pre-existing test data was found.

The plot of stress versus strain is in Appendix E. The plot is linear over the range of loading expected for ACRV model testing. This linear section is almost vertical; therefore, this cable is almost totally inelastic. Young's Modulus and properties can be derived using this plot.

**- Test #5**

- 5.A:** Test 5.A was performed to verify the cable crimping method. Rather than follow procedures 5.A.1 - 5.A.3 and test until failure, the stabilization group determined that a test to insure reliability under the maximum expected load would suffice. The steel cable was rigidly attached on one end, while a 170 pound load was applied to the other.

The crimping method employed proved to be sufficient for testing purposes. The crimped ends of the cables did not loosen or fail under the applied maximum load of 170 pounds. Forces in testing are not expected to exceed 170 pounds as is shown in Appendix F.

- Test #6

- 6.A: Test 6.A was performed to verify attachment methods for the cable system to testbed. The procedure 1.A.1 - 1.A.3 is repeated for the cable and rapid connector link system.

The rapid connector links provided strength and easy attachment. Through visual inspection of the attachment system it was seen that the rapid connector links performed well within requirements.

- Test #7

- 7.A: Test 7.A was performed to verify the design and construction integrity of the parachutes themselves. To achieve this goal, a force was applied to a parachute until it failed. Forces were applied in various directions by securing one half of the fabric in a bench vise, and pulling the other side with a stiff spring scale.

The parachute tested had a two foot diameter. The parachute was not damaged within the range of the 20 pound scale unless the force was applied directly to the beginning of the seam. Additionally, the parachute supported the maximum expected load of 170 pounds in the direction of standard pull. A determination was made that the parachutes were suitable for all normal testing conditions, and it was reasonably certain that no failures would occur.

- Test #8

- 8.A: Test 8.A was performed to verify the attachment method for attaching several parachutes in series. Procedures 8.A.1 - 8.A.3 were followed.

There was no failure under a 170 pound applied load as expected. The design team determined that multiple parachutes could be mounted in series without concern of failure.

- Test #9

9.A: Test 9.A was performed to visually document operation of the point mass system used to deflate parachutes on downstroke. The procedure 9.A.1 - 9.A.4 is followed. Instead of using an underwater camera, video was taken from above the waterline.

For all diameter parachutes, 4 ounces of weight was used to sink the parachutes. The use of heavier weights results in shorter deflation times, but longer inflation times.

- Test #10

10.A: Test 10.A was performed to verify parachute inflation times. The procedure 10.A.1 - 10.A.2 was followed.

Parachute inflation time ranged from 5.3 seconds in the case of the 2 1/2 foot parachute to 2.0 seconds for the 1 foot design. The results of this test show that inflation time decreases with decreasing parachute size.

- Test #11

11.A: Test 11.A was performed to verify attachment of accelerometers and their correct operation. The procedures for 11.A.1 - 11.A.3 were followed. The accelerometers were attached and found to be secure.

The secure attachment eliminated any noise that might affect the accelerometer's output signal. This attachment assured proper response of the accelerometers.

- Test #12

12.A: Test 12.A was performed to establish the baseline dynamic responses with the "clean" model (no attachments). The procedures outlined in 12.A.1 - 12.A.6 were followed. The test was run once to verify accelerometer and data acquisition equipment. The following runs were used to record data.

The clean run provided the baseline dynamic response of the system. This test provided the data for comparison with later tests which included various configurations of the stabilization subsystems. The data acquired during these baseline runs is located in Appendix G.



**- Test #13**

**13.A:** Test 13.A was performed to establish attitude ring effects on the model's stabilization. Six spheres were attached to the eye hooks using two industrial twist ties each to mount the spheres at the bottom of the eyelets. This kept the spheres in contact with the water at all times.

The spheres alone had little effect on the motion of the ACRV model. This test produced a baseline for comparison against possible future tests with attitude spheres and parachute combinations.

**- Test #14**

**14.A:** Test 14.A was devised to establish effects of the ARM on the model's stabilization. The test plan provided for a repeat of procedures 12.A.1 - 12.A.6. Due to time constraints at the test facility, this test was not performed.

No data was collected, but the stabilization team believes that the ARM alone would have little effect on ACRV model motion in the heave direction, and only a small effect in the pitch direction.

**- Test #15**

**15.A:** Test 15.A was conceived to establish effects of attitude spheres and ARM on the ACRV model in the absence of parachutes. Procedures 12.A.1 - 12.A.6 were to have been repeated, with the attitude spheres and ARM attached. Due to time constraints at the test facility, this test was not performed.

No data was collected on the model in this configuration. As in the previous test, the stabilization team believes that the model in this configuration would not react significantly different than the model with only the spheres attached.

**- Test 16**

**16.A:** Test 16.A was devised to establish parachute effects on the model's stabilization. Procedures 12.A.1 - 12.A.6 were to have been repeated for each cell of the matrix (Figure 4.24). Due to time constraints at the test facility, the matrix was not fully completed.

# EFFECTIVENESS OF SINGULARLY SIZED PARACHUTES (3 & 4 POINT ATTACH.)

Sea State Four			
	Series 1	Series 2	Series 3
3, D = 2.5 Ft.	Not Performed	Not Applicable	Not Applicable
3, D = 2.0 Ft.	Not Performed	Not Performed	Not Applicable
4, D = 2.0 Ft.	Not Performed	Not Performed	Not Applicable
3, D = 1.5 Ft.	Not Performed	Not Performed	Not Performed
4, D = 1.5 Ft.	NO	Not Performed	Not Performed
3, D = 1.0 Ft.	Not Performed	Not Performed	YES
4, D = 1.0 Ft.	NO	YES	YES

The effectiveness of each type of parachute was determined through specific testing of each size, both individually, and in series of up to three. In addition, testing was conducted using both three and four attachment points to the model. Each test performed was rated as having significant effect on model motion, or as making no significant impact on motion of the model as compared to baseline response. These ratings are be noted in the above matrix with a simple "yes" or "no." All initial effectiveness testing were performed at scaled sea state 4 conditions.

An explanation of the above matrix follows: the first column lists the number of attachment points to the ACRV model, followed by the diameter of the parachute to be used in that row of testing. The three columns to the right of column one are labeled "Series 1," "Series 2," and "Series 3." These columns represent the number of parachutes connected in series to each attachment point on the ACRV. As an example, the third row represents two individual tests, each using two foot diameter parachutes connected to four attachment points on the model. The first test consisted of one parachute on each connection, the second test was conducted with two parachutes in series on each of the four cables.

Completion of the above matrix yields relative effectiveness information for each size parachute in the worst case condition. Parachutes with little effectiveness may be disregarded in future tests.

FIGURE 4.24

Tests completed were videotaped. The one foot diameter parachutes, both individually and in series were the most thoroughly tested as they provided the smallest inflation time and thus the largest reaction. Inflation time proved to be the limiting factor. Even the one foot parachutes did not inflate in time to provide a significant effect on the model's motion unless they were fitted with stiff wire to hold open the skirt. The largest effect on model motion was achieved by using one foot parachutes in a series of three to a cable, with wire stiffeners and two pounds of weight per cable. The model fitted with four cables in this arrangement demonstrated a profound change in motion as compared to the baseline. This comparison can be made with the data given in Appendix G. Other configurations utilizing smaller numbers of stiffened one foot parachutes resulted in a similar, but less pronounced effect on the ACRV model.

- Test #17

17.A: Test #17.A was devised to establish combined attitude ring and parachute effects on model stabilization. Procedures 12.A.1 - 12.A.6 were to have been repeated using the parachute-attitude sphere combination. Due to time constraints at the test facility this test was not performed.

No data was collected on the model in this configuration. The stabilization team believes that reaction of the model in this configuration would not be significantly different than that of the model fitted with parachutes only.

- Test #18

18.A: Test 18.A was devised to establish attitude ring, ARM, and parachute combination effects on model stabilization. Procedures 12.A.1 - 12.A.6 using the ARM, attitude spheres, and parachutes were to have been repeated. Due to time constraints at the test facility the test was not performed.

No data was collected on the model in this configuration. The stabilization team believes that the addition of the ARM to the configuration stated in test 17.A would not have had significant effect on the motion of the ACRV model except for the possibility of a small damping in pitching motion.



**SECTION V.**

**SUMMARY**

**DESIGN, BUILDING, AND TESTING**  
**OF THE POST LANDING SYSTEMS**  
**for the**  
**ASSURED CREW RETURN VEHICLE**

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**SECTION V. SUMMARY - DESIGN, BUILDING, AND TESTING OF THE POST LANDING SYSTEMS FOR THE ASSURED CREW RETURN VEHICLE**

The 1990-1991 senior-level Mechanical and Aerospace Engineering Design class completed the one-fifth scale design, building, and testing of the post landing egress and stabilization systems for an Apollo Command Module-based ACRV. The objective was to determine the feasibility of: 1) stabilizing the ACRV out of the range of motions which cause seasickness and 2) the safe and rapid removal of a sick or injured crewmember from the ACRV. Work was conducted in the following areas: ACRV model construction, water test facility identification, rapid egress systems, and stabilization control systems.

A one-fifth scale working model of an Apollo Command Module (ACM) derivative was designed and built by the ACRV Model Construction team. The model accommodates the egress and stabilization systems for feasibility studies. The fidelity of the model was established from geometric and dynamic characteristic tests performed on the model. Results indicate small deviations from the specifications provided by Rockwell International. Hardpoint accommodations and seal integrity were maintained throughout the approximately thirty hours of water testing on the egress and stabilization systems.

Stabilization tests on the ACRV model were conducted at the O. H. Hinsdale Wave Research Laboratory at Oregon State University, as recommended by the Water Test Facility Identification team. The testing period was from April 1-5, 1991. The facility accommodated all testing configurations and the staff provided excellent technical support.

The Rapid Egress Systems team designed, built, and tested one-fifth scale models of the Four Link Injured Personnel Egress Mechanism (FLIPEM) and the Two Slider Support Mechanism (TSSM). The FLIPEM provides a safe and rapid removal of a crewmember, confined to a medical couch, from the ACRV floor to the hatch location. The TSSM provides the extension support of the couch platform through the hatch to a distance away from the ACRV. Operational and visualization tests were performed at UCF. Testing was conducted in the areas of lifting force, vertical and horizontal travel distances, and redundancy characteristics for the FLIPEM and extension force, travel distance, and redundancy characteristics for the TSSM. Results indicate the design specifications for both systems were met or exceeded.

The ACRV attitude ring and stabilization system models were designed, built, and tested by the Stabilization Control Systems team. The attitude ring system consists of four to six tether balls attached to the ACRV model directly above the breakline. The stabilization system consists of four arrangements of one to two and a half foot diameter nylon parachutes attached to the ACRV model using elastic or inelastic cables. Testing at Oregon State University was divided into three segments. The first segment was devoted to establishing the baseline dynamic response of the ACRV model to sea states two to four. The second and third segments were devoted to establishing the dynamic responses of the

attitude ring/model and parachute/model combinations in the same sea states, respectively. As seen in the response comparisons, preliminary results show the attitude ring and parachute systems had no effect on reducing the oscillations of the model in sea states two, three, and four.

A concept employing Rocker Stoppers was built and tested at the water test facility to determine the effect a rigid system would have on reducing the oscillations. Two Rocker Stoppers were connected, nose-to-nose, at one end of a long threaded rod. The other end of the rod was connected to a metal plate attached to the model above the breakline. Four of these arrangements were connected to the model. Since the Rocker Stoppers are made of rigid plastic, they performed the same work on the upstroke as on the downstroke. This configuration was tested in a simulated sea state four (1.2 ft amplitude, 0.45 Hz) and the response compared with that from the clean model in the same sea state. The results indicate that a rigid system in this configuration does reduce the oscillation the model experiences. The frequency of the pitch motion dropped from 0.45 Hz for the clean model to 0.40 Hz with the Rocker Stoppers attached. This reduction is below the range (0.45 - 1.1 Hz) associated with seasickness.

There are several recommendations in the area of post landing operations associated with the Assured Crew Return Vehicle that are appropriate for future design projects. Integrated wave testing involving the egress system and the attitude ring spheres and mattress needs to be examined. Another project would entail building and testing a full scale egress system based on the FLIPEM design. Examining the floatation and wave motion characteristics of other ACRV configurations, such as the SCRAM and HL-20, and comparing them to a mathematical model is suggested. Finally, examination of the use of a rigid stabilization system like the Rocker Stopper concept for motion reduction has demonstrated merit.

## **REFERENCES**

1. Froelich, W., "Space Station, The Next Logical Step," Government Printing Office, Washington D.C., NAS 1.19.213, February 13, 1985, p. 38.
2. Herman, D., "Space Station Architectural Concepts and Functional Capability," Space Applications at the Crossroads: 21st Goddard Memorial Symposium ed. J. McElroy and E. Heacock, (San Diego: Univelt, Inc.) 1983, p. 257.
3. Hosterman, K., "Post Landing Designs for the Assured Crew Return Vehicle," Department of Mechanical and Aerospace Engineering, University of Central Florida, Orlando, Fl., 1990.
4. Baker, W., Westine, P., and Dodge, F., Similarity Methods in Engineering dynamics, Hayden Book, Rochelle Park, NY., 1978, p. 92.
5. Beer, F., and Johnston Jr., E., Vector Mechanics for Engineers, 4th ed., McGraw-Hill, New York, NY., 1984.
6. Smith, R., Materials of Construction, 2nd ed., McGraw-Hill, New York, NY., 1973.
7. Lubin, G., ed., Handbook of Fiberglass and Advanced Plastic Composites, R. E. Krieger Publishing Co., Huntington, NY., 1969, p. 303-305.
8. Wiley, J., The Fiberglass Repair and Construction Handbook, 2nd Edition, Tab Books Inc., Blue Ridge Summit, Pa., 1988.
9. Davidson Laboratory, Brochure, A Research Center with an Education Mission, Hoboken, NJ., February, 1990.
10. O.H. Hinsdale Wave Research Laboratory, Brochure, Oregon State University, Corvallis, Or..
11. Offshore Technology Resource Center, Press Release, Texas A&M University, Tx..
12. Johnson, P., Director, Offshore Technology Research Center, Texas A&M University, Tx., Interview, October, 1990.
13. Parker, G., ACRV Program Manager, Kennedy Space Center, Fl., Briefing to Engineering Design Class (EML 4501-01), August 28, 1990.
14. Hosterman, K., Graduate Student Program Manager, UCF Lecture, NASA/USRA Advanced Space Design Program, University of Central Florida, Fall, 1990.



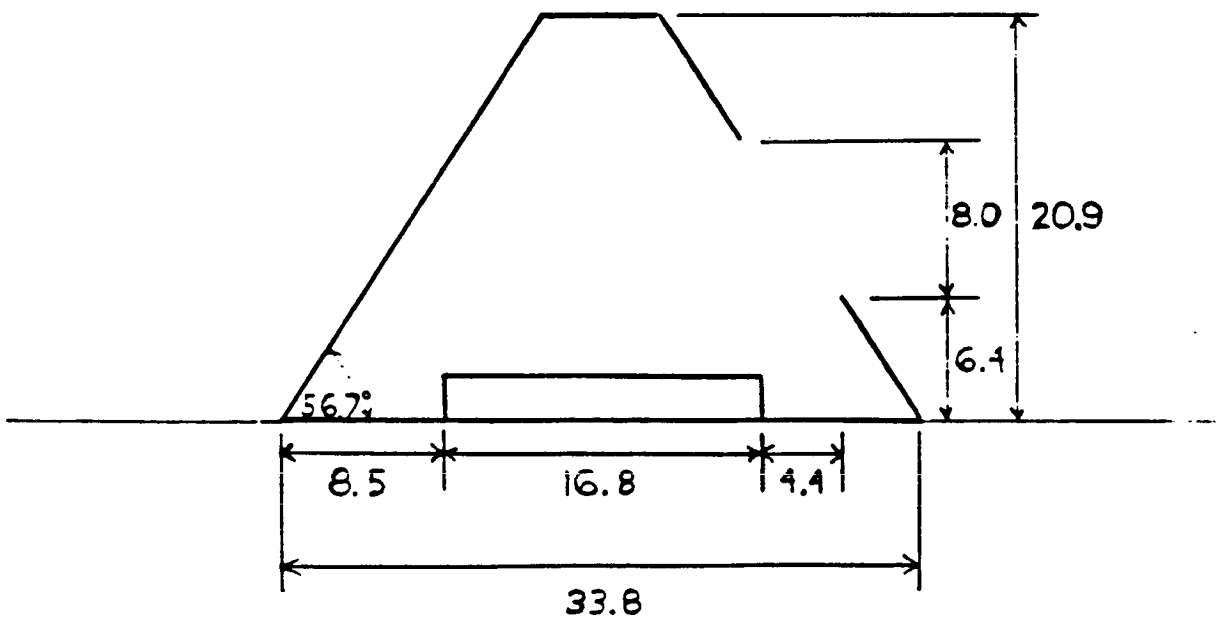
15. Smith, W., Principles of Materials Science and Engineering, McGraw-Hill, New York, NY., 1986, p. 476-478.
16. Beer, F., Johnston Jr., E., Vector Mechanics for Engineers, McGraw-Hill, New York, NY., 1984, p. 19-27.
17. Shigley, J., Uicker, J., Theory of Mechanics and Mechanisms, McGraw-Hill, New York, NY., 1980, p. 12-15.
18. Johnson Space Center, ACRV Background, No Date, p. 3.
19. Poynter, D., The Parachute Manual: A Technical Treatise on the Parachute, Parachuting Publications, Santa Barbara, Ca., 1977.
20. Dimarogonas, A., Computer Aided Machine Design, Prentice Hall, New York, NY., 1989.
21. Crowe, C., Roberson, J., Engineering Fluid Mechanics, Houghton Mifflin Company, Boston, Ma., 1985.
22. James, M., Smith, G., Welford, J., and Whaley, P., Vibration of Mechanical and Structural Systems, Harper and Row, New York, NY., 1989.
23. Yeung, R., "A Hybrid Integral-Equation Method for Time-Harmonic Free-surface Flow", First International Conference on Numerical Ship Hydrodynamics, Office of Naval Research, October 20-22, 1975.
24. Trietley, H., Transducers in Mechanical and Electronic Design, Marcel Dekker, Inc., New York, NY., 1986.
25. Beckwith, T., Marangoni, R., Mechanical Measurements, Addison-Wesley Publishing Company, Reading, Ma., 1989.
26. Parker, G., ACRV Program Manager, Kennedy Space Center, Fl., Interview, November 8, 1990.
27. Knacke, T., "Decelerator Systems Engineering", T.W. Knacke Lectures, University of Minnesota, Sandia National Laboratories, July, 1985, p. 5-30.

**APPENDIX A**

**OVERALL CAPSULE DIMENSIONS**

**APPENDIX A**

**OVERALL CAPSULE DIMENSIONS**



**APPENDIX B**  
**ESTIMATED COSTS**

## APPENDIX B

### ESTIMATED COSTS

<u>PART</u>	<u>NEED</u>	<u>ITEM COST</u>	<u>TOTAL COST</u>
SLIDERS	4	\$10 - \$20	\$40 - \$80
ELECTRIC MOTOR (24V)	1	\$5.00	\$5.00
SOLENOID	2	\$5.00	\$10.00
RATCHETS	2	\$5.00	\$10.00
PULLEYS GEARS	10	\$3.00	\$30.00
GAS CYLINDER	2	\$8 - \$10	\$16 - \$20
SPOOLS	2	\$1.00	\$2.00
NUTS/BOLTS			\$5.00
STEEL RODS	4	\$1.00	\$4.00
MONOFILAMENT	1	\$2.00	\$2.00
SPRINGS	3	\$1.00	\$3.00
1/8" THICK ALUMINUM PLATE	2 FT <sup>2</sup>		\$12.00
1/4" THICK ALUMINUM PLATE	2 FT <sup>2</sup>		\$5.00
1 X 1 X 1/8" ALUMINUM ANGLE	4 FT		\$6.00
MISCELLANEOUS			\$50.00
<hr/>			
TOTAL			\$200 - \$244

**APPENDIX C**

**ATTITUDE RING BUOYANCY ANALYSIS**

### Appendix C: Attitude Ring Buoyancy Analysis

The analysis for determining the buoyancy force of the model ACRV is presented below. Refer to Appendix D for a diagram involving the direction of the forces applicable in the buoyancy analysis.

Force Balance:

$$\begin{aligned}\Sigma F_x &= 0 = F_b(x) - W \\ F_b(x) &= W\end{aligned}$$

Buoyancy Force: (Roberson/Crowe, pp.54-55)

$$\begin{aligned}F_b(x) &= \rho * g * V(x) \\ F_b(x) &= \gamma * V(x)\end{aligned}$$

Where:

- $\rho$  = density of water
- $V(x)$  = volume of water displaced as a function of  $x$
- $g$  = acceleration due to gravity, 386.4 in/sec
- $\gamma$  = specific weight of water as a function of  $x$

Volume:

An expression for volume displaced must now be determined as a function of  $x$ . Refer to Appendix D for variable names and values which pertain to the ACRV model (for the volume equations see Appendix D). Once the expressions for volume have been determined, the actual buoyancy required of the attitude ring can be determined.

First, the model must be constructed and placed in water to determine its natural buoyant force. Using the equations for volume as a function of  $x$ , the volume displaced must be calculated. This volume,  $V_i$ , multiplied by the specific weight of the water will yield the natural buoyancy of the model. The attitude ring must provide the additional buoyancy to raise the model ACRV to a point where the bottom of the hatch is at least 7.2 inches above the water. To determine this buoyancy, first determine how high the model must be raised to satisfy the previously mentioned criterion (distance,  $d$ ). Using the expressions for volume, calculate the volume displaced,  $V_f$ , when the model ACRV is at a point where the distance of the hatch above the waterline is at least 7.2 inches. Calculate  $(V_i - V_f)$  and use this volume multiplied by the specific weight of water to find the required buoyancy of the attitude ring,  $F_{AR}$ . This provides the information needed for the ring to now be sized.

**APPENDIX D**

**ATTITUDE RING VOLUME CALCULATIONS**



## Appendix D: Attitude Ring Volume Calculations

The volume of the ACRV is found by integrating along its height (the X axis). The total volume is considered in two sections. The top funnel-shaped part is volume I ( $V_I$ ). The bottom spherical section is volume II ( $V_{II}$ ). Both sections are integrated as disks of thickness  $dx$ .

The funnel part ( $V_I$ ), is integrated from  $x = 0$  at the widest part of the funnel to  $x = L_f$ , the height of the funnel as:

$$V_I = \int_0^{L_f} \pi(r(x))^2 dx \quad (1)$$

Where the differential disk radius is:

$$r(x) = \left( \frac{r_{1f} - r_{1i}}{L_f} \right) \cdot x + r_{1i} \quad (2)$$

The integrated volume is then:

$$V_I(x) = \pi \left[ \frac{(r_T - r_B)^2}{3L_f^2} x^3 + \frac{r_B(r_T - r_B)}{L_f} x^2 + r_B^2 x \right]_0^{L_f} \quad (3)$$

Where:

$r_B$  = the radius of the widest part of the funnel  
 $r_I$  = the radius of the narrowest part of the funnel  
 $L_f$  = the height of the funnel

Substituting in the dimensions of the model:

$r_B$  = 17.4 inches  
 $r_I$  = 3.6 inches  
 $L_f$  = 19.2 inches

$V_I$  = 8.593 cubic feet

The spherical part ( $V_{II}$ ) of the ACRV is integrated from  $x = 0$  at the edge of the sphere to  $x = L_s$ , the height of the sphere as:

$$V_{II} = \int_0^{L_s} \pi(r(x))^2 dx \quad (4)$$

Where the differential disk radius squared is:

$$(r(x))^2 = r_s^2 - (r_s - x)^2 \quad (5)$$

The integrated volume is then:

Where:

$r_s$  = the radius of the sphere forming the bottom  
 $L_s$  = the height of the spherical part

$$V_{II} = \pi \left[ r_s^2 x - \frac{x^3}{3} \right]_0^{L_s} \quad (6)$$

Substituting in the dimensions of the model:

$$r_s = 24.5 \text{ inches}$$

$$L_s = 7.2 \text{ inches}$$

$$V_{II} = \underline{2.083 \text{ cubic feet}}$$

The total volume is then the sum of  $V_I$  and  $V_{II}$ :

$$V_I = \underline{10.676 \text{ cubic feet}}$$

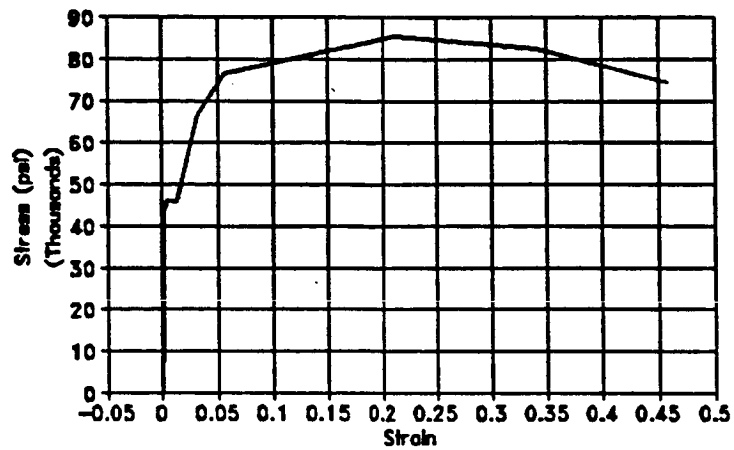
The equations are also used to calculate the buoyancy of the ACRV model by substituting the desired values for  $x$ , the desired draft, into each of the equations.

## **APPENDIX E**

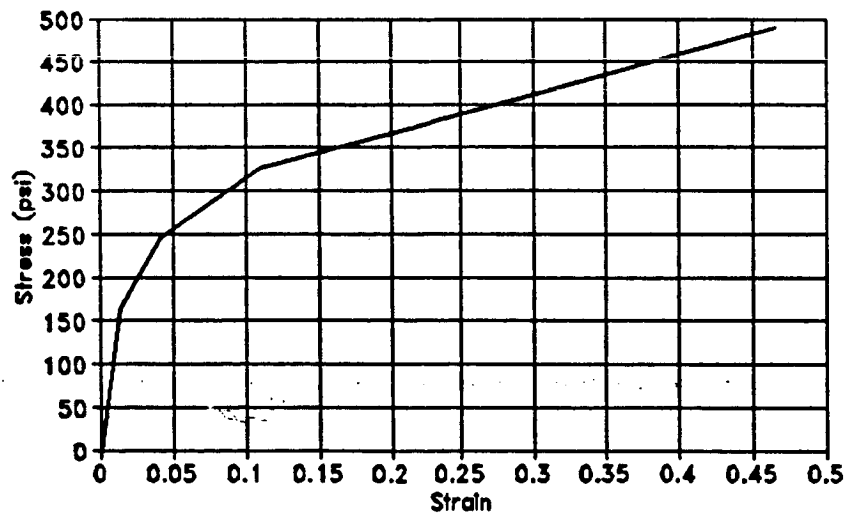
### **PROPERTIES OF INELASTIC AND ELASTIC CABLES**

**Appendix E**  
**Properties of inelastic and elastic cables.**

**Inelastic Cable**  
**Stress versus Strain**



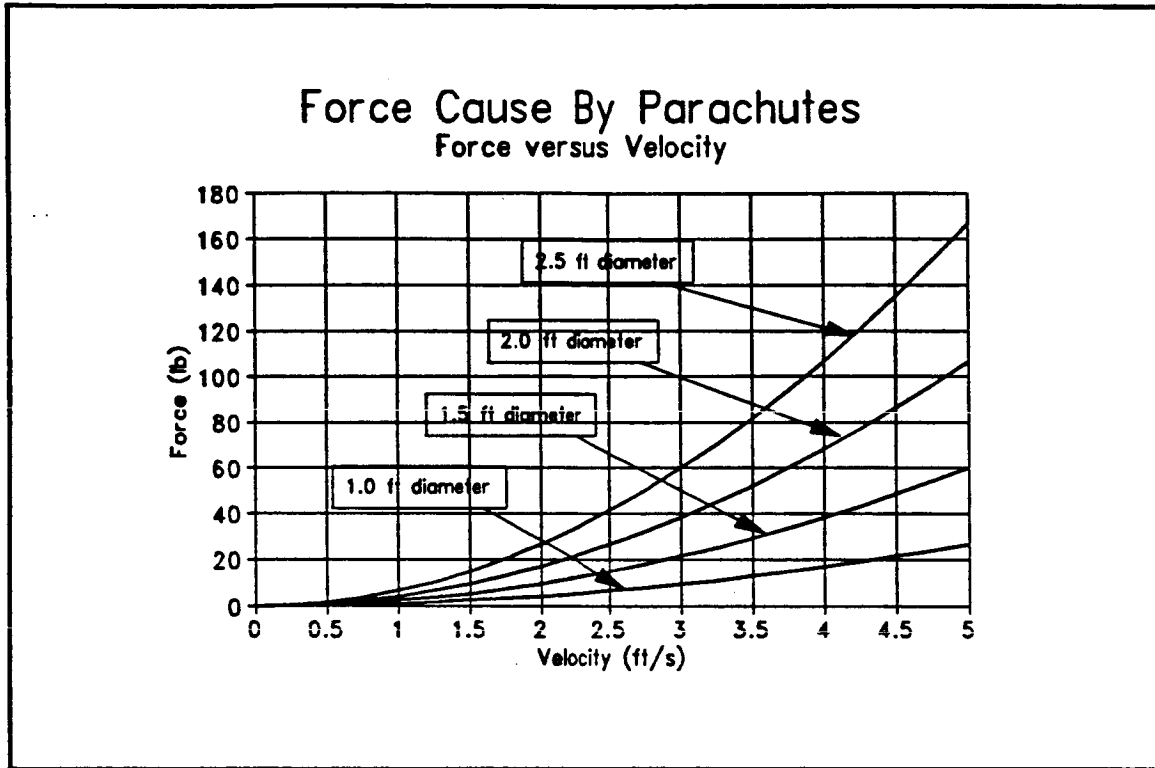
**Elastic Cable**  
**Stress versus Strain**



## **APPENDIX F**

### **EXPECTED DRAG FORCES PRODUCED BY PARACHUTES**

**Appendix F**  
**Expected Drag Forces Produced by Parachutes**



The plot above has been generated assuming a coefficient of drag of 1.4. The following equation was used:

$$F_D = \frac{1}{2} C_D \rho A V^2 = \frac{\pi}{8} C_D \rho D^2 V^2$$

The maximum velocity expected is 5 feet per second. This produces a maximum force of approximately 170 pounds.

## **APPENDIX G**

### **RUN DATA**

**Runs 1 to 4: Clean Model at Different Sea States**

**Run 8: Attitude Spheres at Sea State 4**

**Runs 11, 12, 14, 16, Different Configurations of DUPS at Sea  
19, 26, and 27: State 4**

## **APPENDIX G**

### **RUN DATA**

**Runs 1 to 4: Clean Model at Different Sea States**

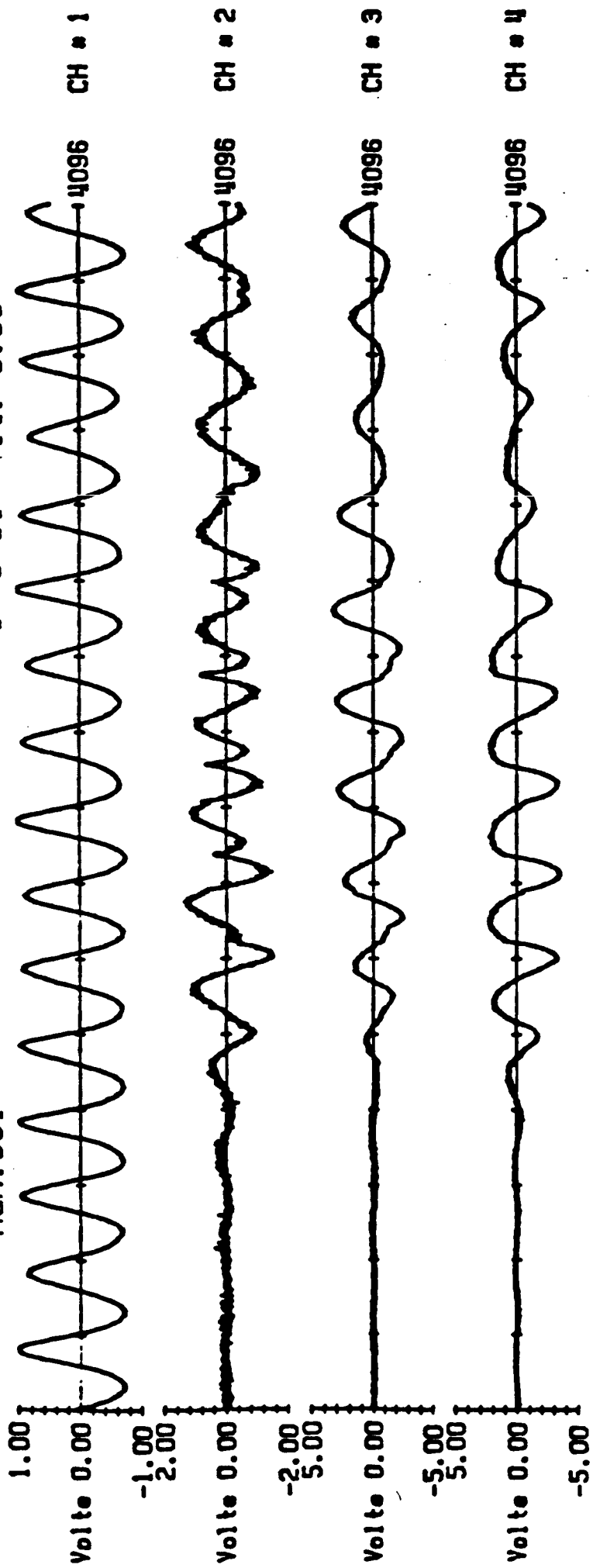
**Run 8: Attitude Spheres at Sea State 4**

**Runs 11, 12, 14, 16, Different Configurations of DUPS at Sea  
19, 26, and 27: State 4**



Run.001

4- 5-91 14: 0:50

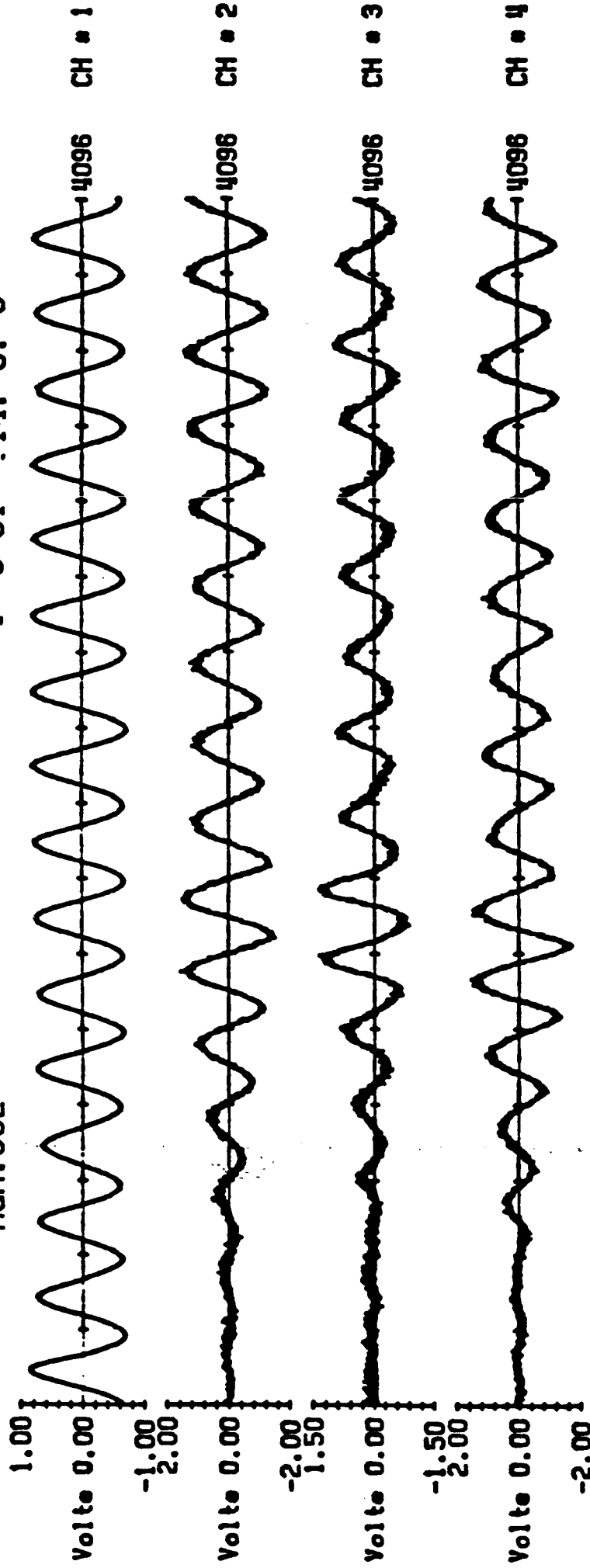


Channel 1: Wave Action  
Channel 2: Heave Motion  
Channel 3: Surge Motion  
Channel 4: Pitch Motion

Frequency: 1.1 Hertz  
Wave Height: 0.4 feet  
Sea State: 2

Run.002

4- 5-91 .14: 3: 0

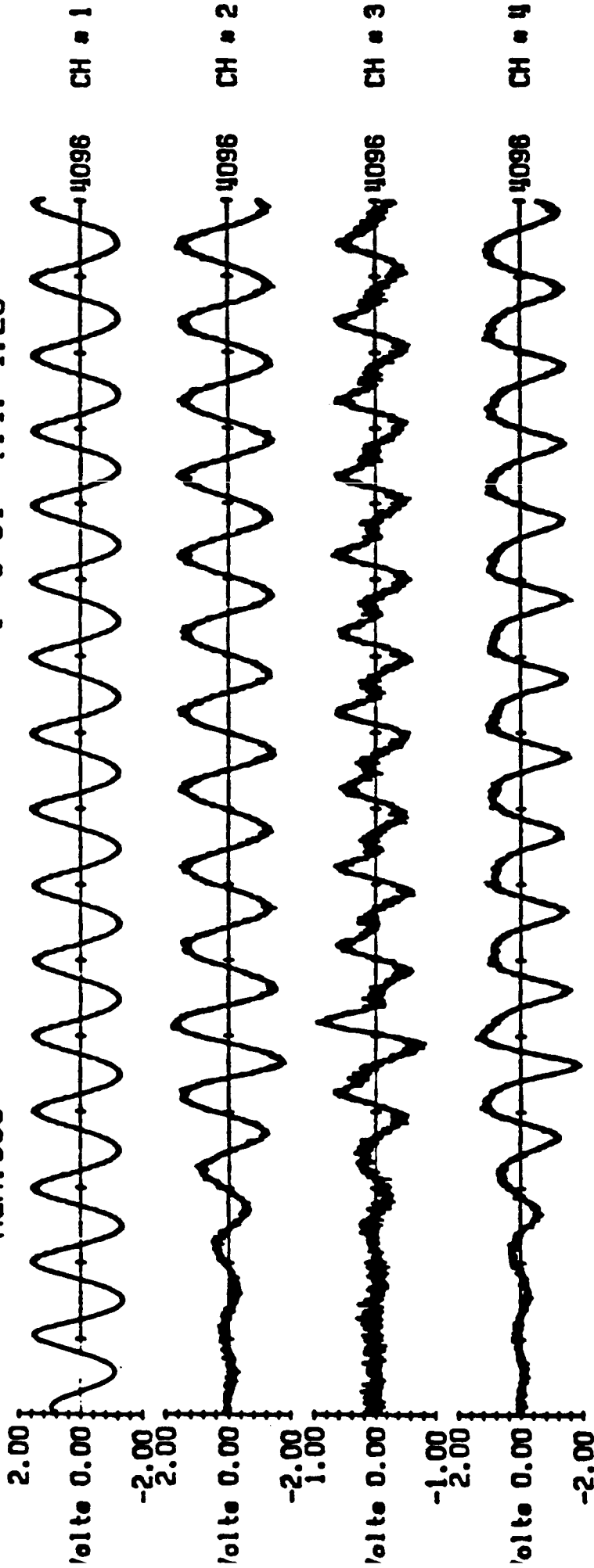


Channel 1: Wave Action  
Channel 2: Heave Motion  
Channel 3: Surge Motion  
Channel 4: Pitch Motion

Frequency: 0.75 Hertz  
Wave Height: 0.4 feet  
Sea State: 2

Run.003

4- 5-91 .14: 4:26

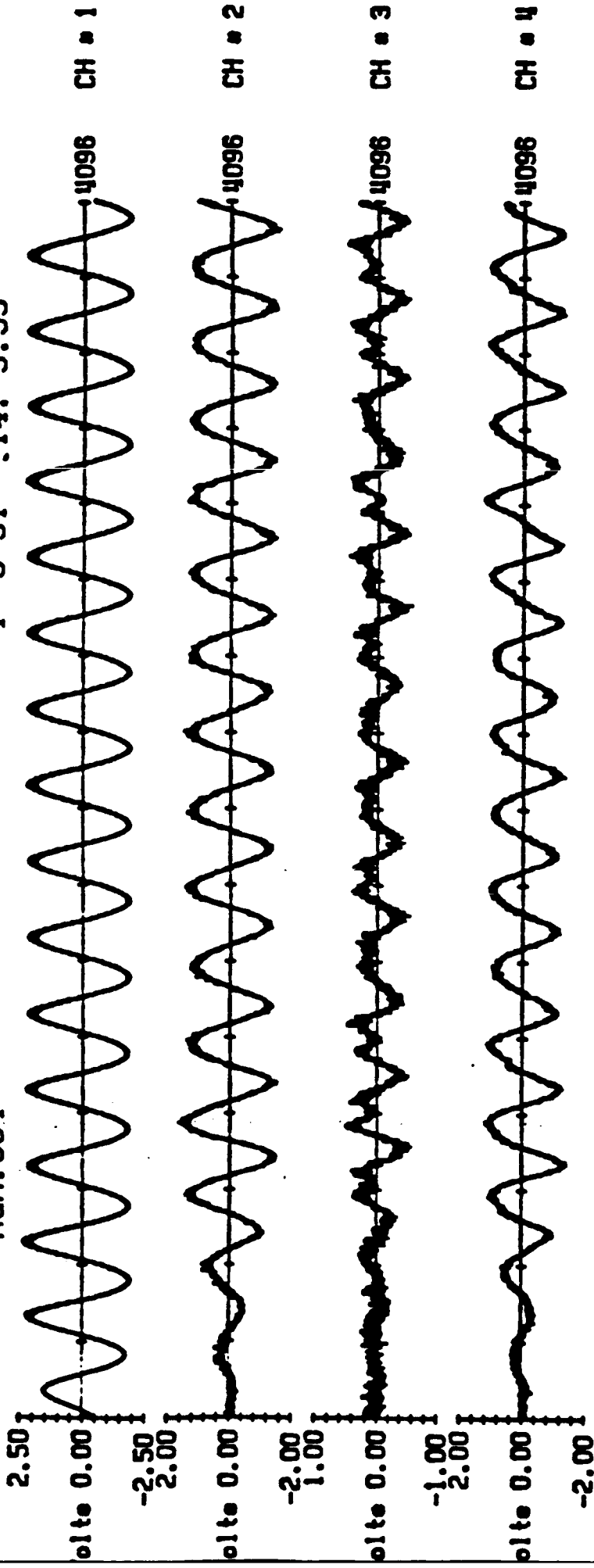


Frequency: 0.56 Hertz  
Wave Height: 0.4 feet  
Sea State: 3

Channel 1: Wave Action  
Channel 2: Heave Motion  
Channel 3: Surge Motion  
Channel 4: Pitch Motion

Run.004

4- 5-91 .14: 5:39



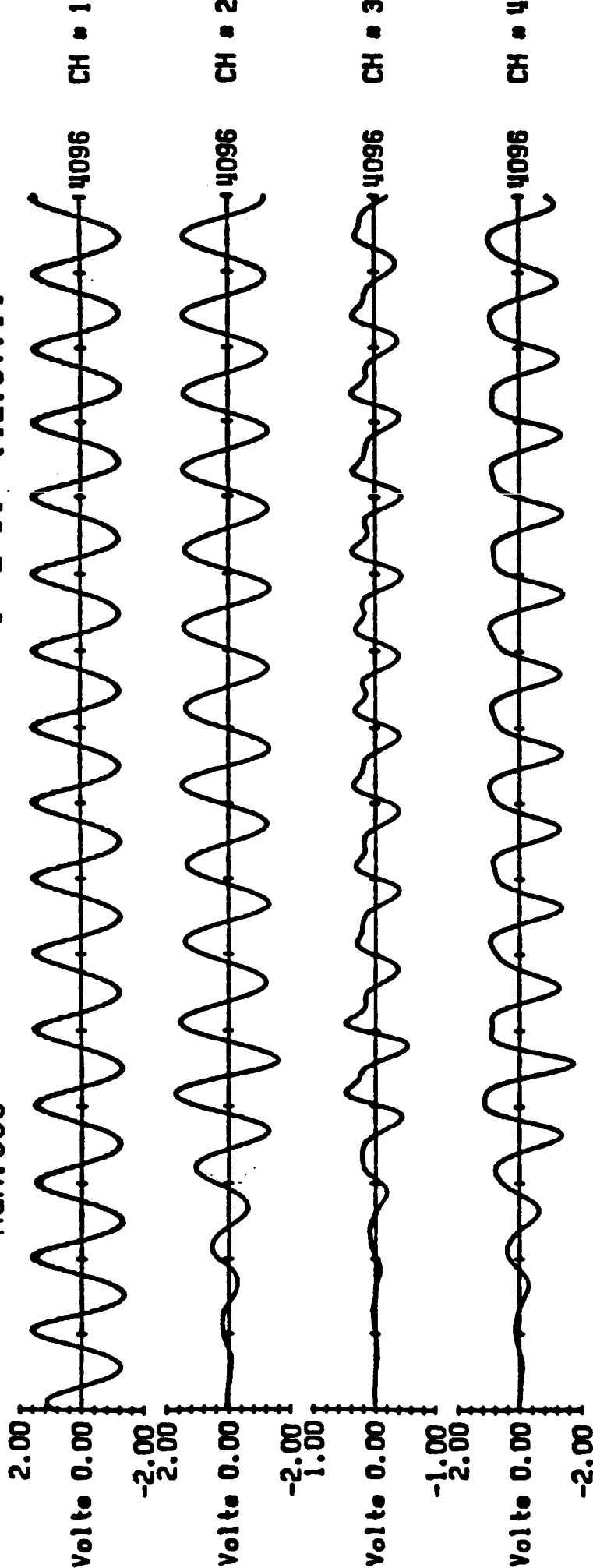
Frequency: 0.45 Hertz  
Wave Height: 1.2 feet  
Sea State: 4

Channel 1: Wave Action  
Channel 2: Heave Motion  
Channel 3: Surge Motion  
Channel 4: Pitch Motion

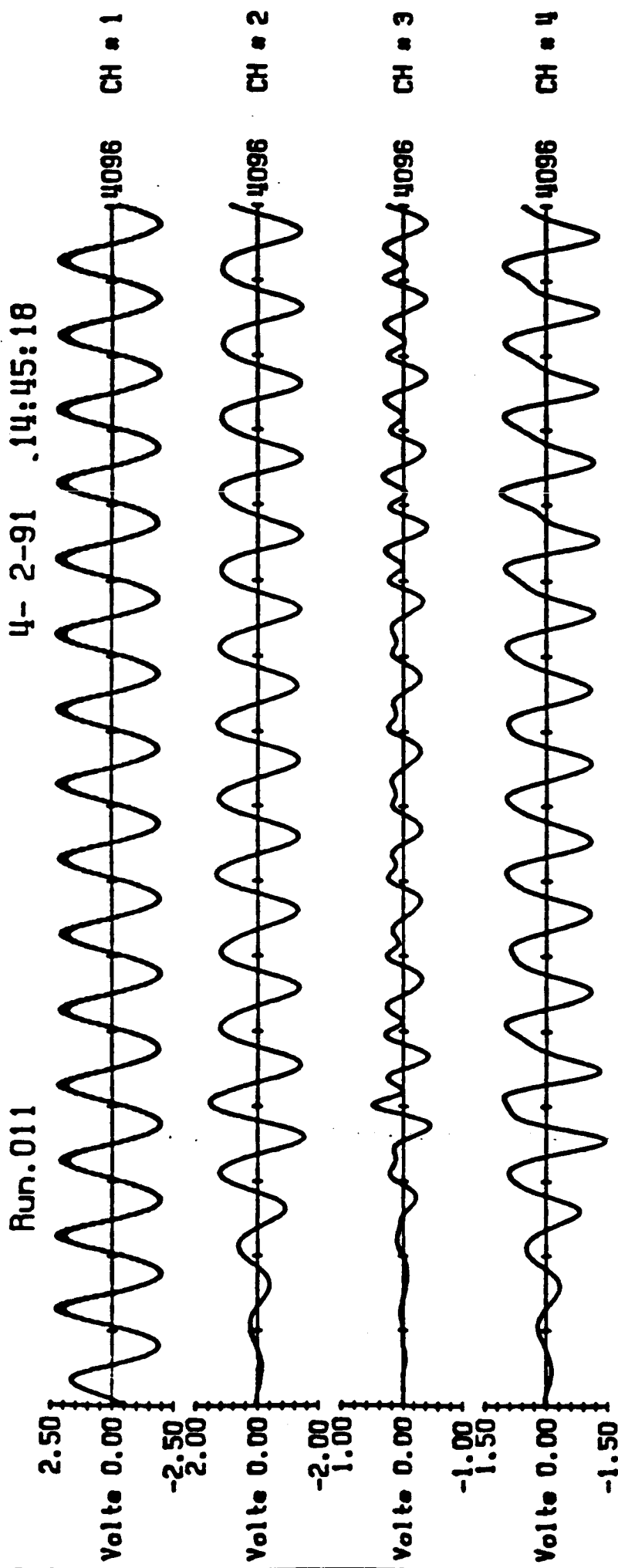
# Configuration: 6 Attitude Spheres

Run.008

4- 2-91 .12:37:14

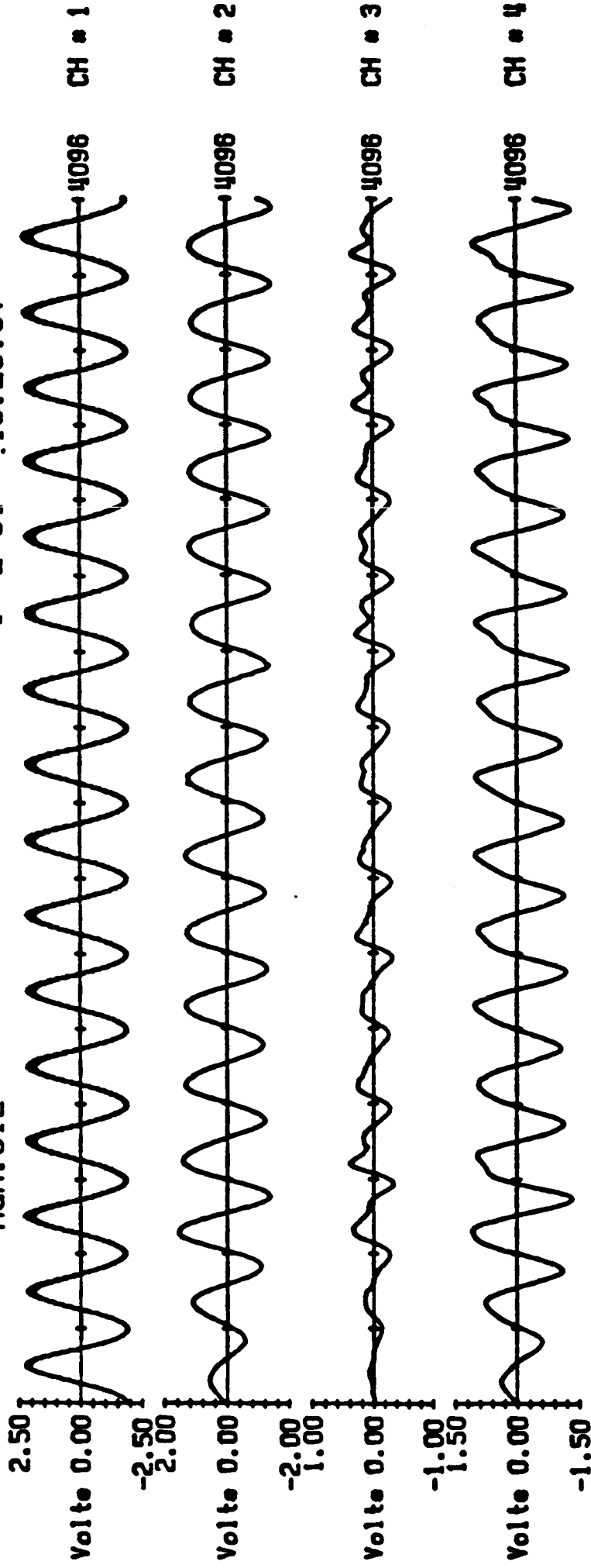


Configuration: 4 1 foot diameter parachutes  
with 8 ounce weights



Configuration: 4 1.5 foot diameter parachutes  
with WRAP1 and 8 ounce weights

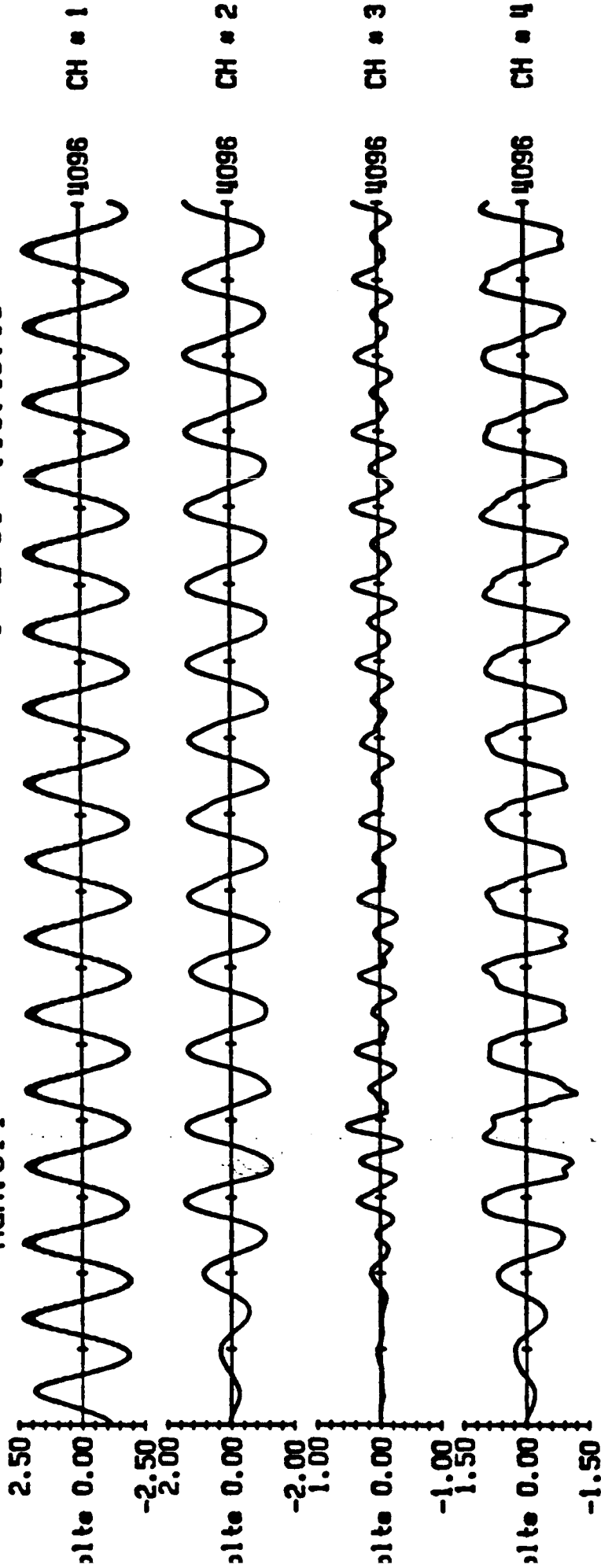
Run.012 4- 2-91 15:29:37



Configuration: 4 1.5 foot diameter parachutes  
with WRAP1 and 24 ounce weights

Run. 0114

4- 2-91 .16:45:19

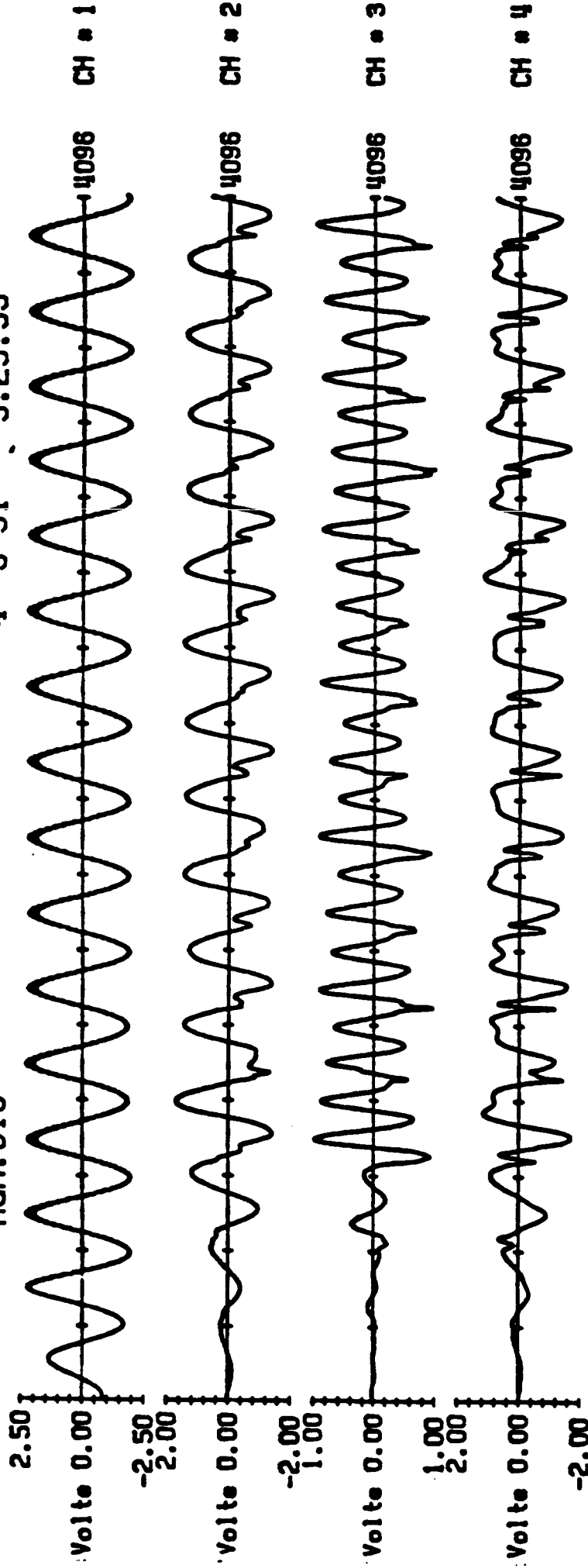




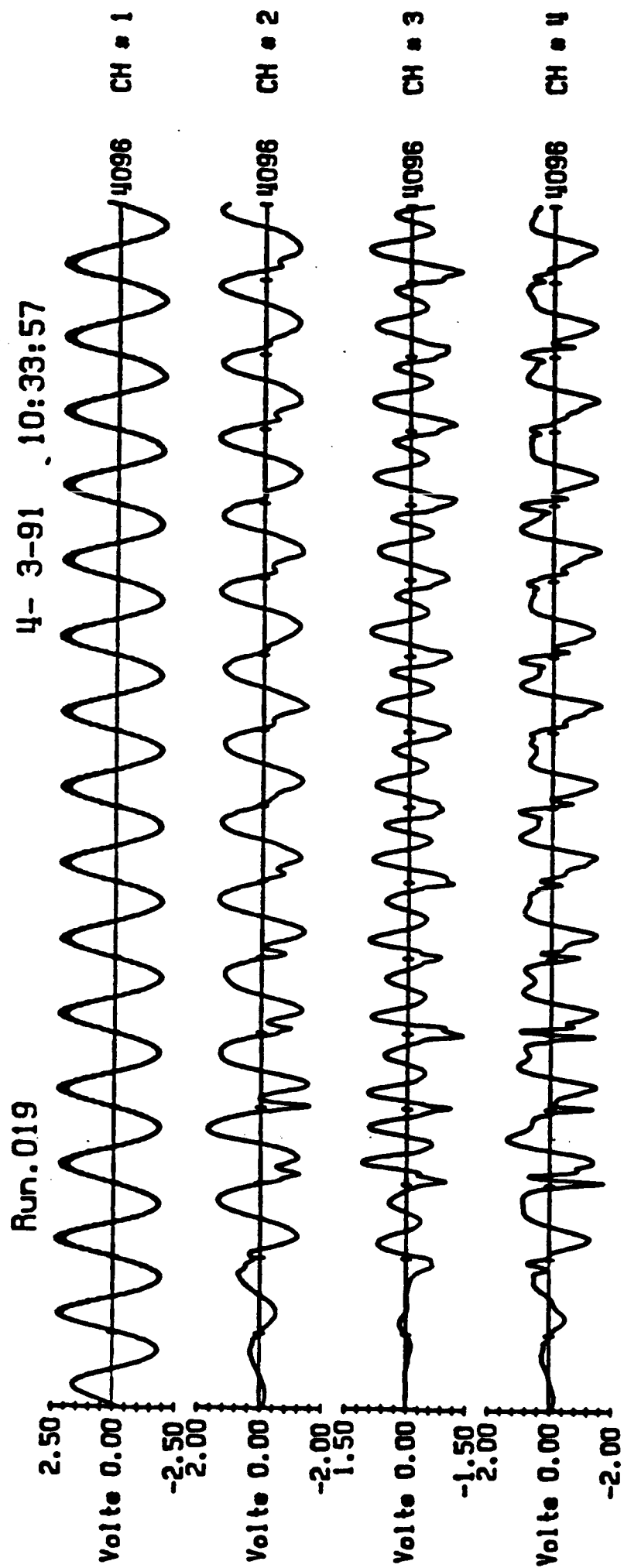
Configuration: 4 1 foot diameter parachutes with  
24 ounce weights

Run. 016

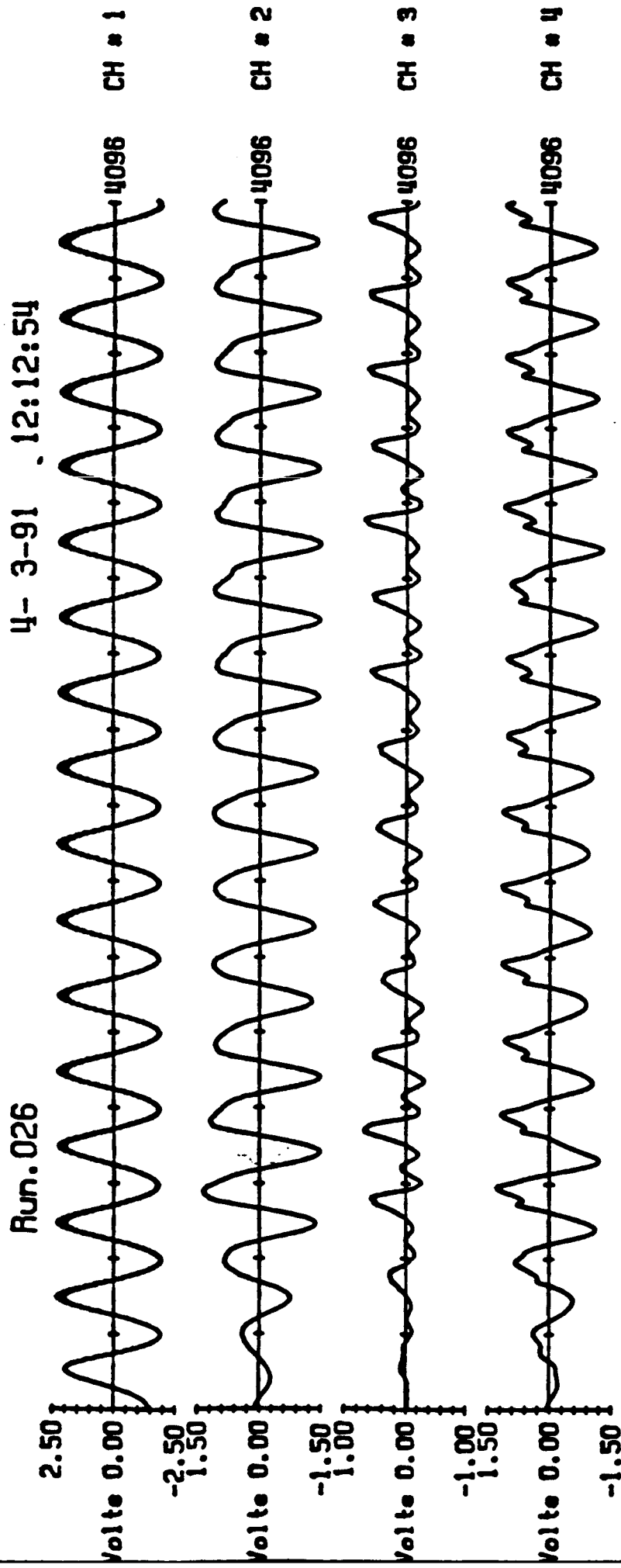
4- 3-91 9:29:53



Configuration: Series of two 4 1 foot diameter  
parachutes with WRAP2 and 36  
ounce weights

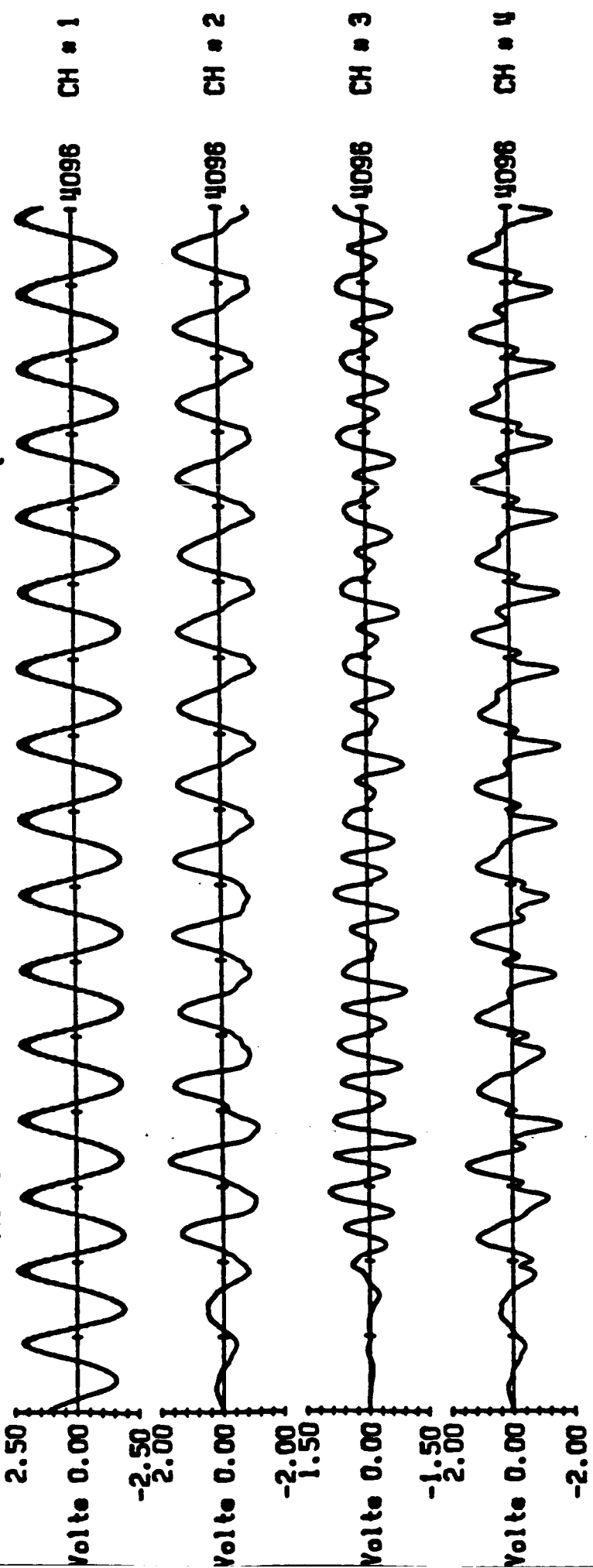


Configuration: Series of three 4 1 foot diameter  
parachutes with WRAP2 and 36  
ounce weights - elastic cables



Configuration: Series of three 4 1 foot diameter  
parachutes with WRAP2 and 36  
ounce weights - series of 2  
elastic cables

Run. 027 4- 3-91 12:30:41



**APPENDIX H**  
**DECISION MATRICES**

# CG/MASS MOMENT

	Design Parameters		Weight		Enable Splitting Vehicle		Models CG		Models Mass Moment		Variable CG		Variable Mass Moment		Ease of Construction		Separate CG/ Adjustment		Cost		Totals
Weight Factors	5	4	5	4	5	4	5	4	5	4	4	3	4	3	4	1					
Point Mass	2	10	10	2	10	2	10	2	10	2	8	2	8	2	6						264
Periph. Weight	9	10	10	6	10	6	10	6	10	6	8	2	8	2	8						321
Vertical Rod	7	5	6	10	6	8	8	8	8	5	9										296
Circular Plates	9	10	10	10	10	10	7	9	7												389

# MATERIALS

Weight Factors	Design Parameters										Totals
	Strength	Durability	Workability	Strength to Weight	Cost	Repairability	Reliability	Waterproof	Rigidity		
5	4	4	5	1	5	5	5	5	5		
8	8	7	5	9	7	8	6	8			265
9	6	8	6	7	7	7	6	8			264
7	7	6	8	6	4	8	8	7			260
9	9	8	7	6	9	8	9	9			311

# ATTACHMENT

Weight Factors	Design Parameters								Totals
	Strength	Durability	Alignment	Ease of Operation	Cost	Reliability	Waterproof		
	4	3	4	2	1	4	4		
Dowel Pins	8	7	9	6	8	7	9	218	
Magnets	7	7	8	3	3	7	9	189	
Pins/Plates	9	8	9	8	9	8	9	234	



# DESIGN GROUP OPTIONS

WEIGHT FACTORS    MODIFY EXISTING POOL    CONSTRUCTION OF PERMANENT FACILITY    USING EXISTING FACILITY

DESIGN PARAMETERS					
AVAILABILITY	5		6	1	8
COST	5		5	1	7
RELIABILITY	3		3	10	10
RETESTING	3		6	9	4
ACCURACY	4		4	8	10
INTERFERENCE	4		3	8	9
EXPERIENCE	3		1	1	10
LOCATION	5		10	10	2
DIMENSIONS	5		9	10	10
TOTALS			208	234	283*

Matrix 2.1



## LIFT MECHANISMS

	DESIGN PARAMETERS	DEPENDABILITY	SIMPLICITY	FEASIBILITY	SAFETY	WEIGHT	CONTROLLABILITY	COST	RETRACTABILITY	STABILITY	POWER REDUNDANCY	EASE OF MAINTENANCE	ACCESSIBILITY TO COUCH	EASE OF OPERATION	TIME EFFECTIVENESS	
Weight Factors	5	4	5	4	4	3	3	3	2	5	5	4	5	4		Totals
IRONING BOARD	6	7	6	5	8	5	8	5	7	5	6	10	9	8		349
DUAL SCISSOR JACK	6	7	8	8	6	10	7	9	8	8	6	10	9	7		417
PISTON CYLINDER	5	8	5	7	8	6	5	7	7	7	7	10	9	7		379
ROLLER LINK	5	5	5	8	6	5	8	5	5	5	7	10	9	8		351
INCLINED PLANE	6	6	8	7	6	10	5	8	8	8	5	5	9	7		375
FLIPEM	7	8	8	8	7	7	8	8	8	8	8	10	9	8		433

Optimal Solution = ✓

## RESTRAINT MECHANISMS

	DESIGN PARAMETERS												
		Dependability	Simplicity	Safety	Accessibility	Weight	Feasibility	Cost	Ease of Maintenance	Remote Operation	Ease of Operation	Time Effectiveness	
Weight Factors	5	4	4	3	3	3	2	2	4	5	3		Totals
Latch/Lock	8	9	10	5	9	5	10	9	3	5	7		269
Cable/Lock	6	5	10	5	6	7	7	5	5	7	10		253
✓ Hook/Lock	9	8	10	9	7	9	6	6	8	8	10		318

Optimal Solution = ✓

# MATERIALS

✓

	DESIGN PARAMETERS						
	Cost	Workability	Weight	Availability	Strength	Water Resistance	
Weight Factors	3	5	4	5	4	5	Totals
Aluminum	9	9	9	10	9	10	244
Steel	9	7	5	10	10	10	222
Wood	10	8	7	10	8	7	220

Optimal Solution = ✓

Matrix 4.1

	WEIGHT	ACCURACY	COST	RESPONSE	MAINTAINABILITY	RELIABILITY	REPAIRABILITY	SAFETY	DEPLOYABILITY	TRANSPORTABILITY	INTEGRATION	CONSTRUCTION	TOTAL
WT. FACTOR	1	5	3	4	2	4	3	1	2	2	3	5	
STYROFOAM	8	6	8	6	2	4	3	7	4	2	8	3	173
INNERTUBE	10	10	5	10	7	7	8	8	2	8	4	3	236
BALSA WOOD	4	4	2	5	3	5	4	4	4	2	5	5	144
RIGID FOAM	6	8	2	8	10	8	3	8	6	4	7	4	214
INFLAT. SPH	10	7	8	5	10	8	2	9	8	8	8	10	262

## Attitude Ring Decision Matrix

	WEIGHT	ACCURACY	COST	FLEXIBILITY	MAINTAINABILITY	RELIABILITY	REPAIRABILITY	SAFETY	DEPLOYABILITY	TRANSPORTABILITY	INTEGRATION	CONSTRUCTION	TOTAL
WT. FACTOR	4	1	3	4	4	4	3	3	4	2	3	5	
FABRIC	9	8	4	8	2	3	7	8	2	10	4	2	203
HINGED PLATE	2	2	3	4	4	8	4	2	7	4	4	1	154
UMBRELLA	5	6	2	5	5	5	5	4	8	6	4	3	190
ROCKER STOP	4	2	10	2	10	10	8	9	10	5	4	10	299

Matrix 4.2

## Parachute Decision Matrix

	WEIGHT	ELASTICITY	COST	FLEXIBILITY	MAINTAINABILITY	RELIABILITY	REPAIRABILITY	SAFETY	LINEARITY	TRANSPORTABILITY	INTEGRATION	CONSTRUCTION	TOTAL
STIFF:													
WT. FACTOR	5	4	3	0	2	4	1	4	0	2	0	5	
STEEL	2	7	8	0	5	9	8	5	0	8	0	8	192
GRAPHITE	6	8	3	0	4	8	2	7	0	10	0	4	181
HEAVY MONO	6	1	8	0	7	4	5	9	0	8	0	8	185
ELASTIC:													
WT. FACTOR	5	4	3	0	2	4	1	4	5	2	0	5	
RUBBER	5	8	8	0	6	5	7	6	3	8	0	8	215
LIGHT MONO	7	2	9	0	2	4	8	7	4	5	0	9	201
SPRING	2	9	3	0	3	9	3	5	9	3	0	3	186

## Cable Decision Matrix



CONTACT:

	WEIGHT	SENSITIVITY	COST	FLEXIBILITY	MAINTAINABILITY	RELIABILITY	REPAIRABILITY	SAFETY	LINEARITY	TRANSPORTABILITY	INTEGRATION	RESPONSE	TOTAL
WT. FACTOR	5	4	3	4	2	4	1	4	5	2	4	0	
LVDT	3	10	1	1	1	7	4	3	9	3	2	0	167
VIBROMETER	2	5	3	3	3	3	3	6	6	6	4	0	154
ACCEL' METER	9	7	5	9	7	6	1	9	3	9	8	0	264
WT. FACTOR	2	4	3	4	2	4	1	2	5	2	4	5	
LASER	5	8	1	2	2	2	1	3	8	3	7	9	191
VIDEO CAM	4	4	7	9	5	8	1	3	2	3	5	9	211
VIEW GRID	2	2	9	4	8	10	9	9	2	9	5	2	196

NO-CONTACT:

# Test Equipment Decision Matrix